RM L52L26b

RESEARCH MEMORANDUM

TRANSONIC WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF ASPECT RATIO, SPANWISE VARIATIONS IN SECTION THICKNESS RATIO, AND A BODY INDENTATION ON THE AERODYNAMIC CHARACTERISTICS OF A 45° SWEPTBACK WING-BODY COMBINATION

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Comparisons have been made of the aerodynamic characteristics of six wing-body configurations with 45° sweptback wings differing in aspect ratio and spanwise variations in thickness ratio, with two body shapes. The results were obtained in the Langley 8-foot transonic tunnel for Mach numbers from 0.80 to 1.10, angles of attack from 0° to 12°, and Reynolds number of about 1.6×10^6.

The comparisons show that, at subsonic speeds, the favorable effect of increasing the aspect ratio from 4 to 6 more than offsets any adverse effects of moderately thickening the inboard sections of a wing as required to obtain the equivalent structural strength with this higher aspect ratio. At supersonic test Mach numbers, the favorable effects of increasing the aspect ratio are about the same as the adverse effects of thickening the inboard sections.

Indenting the body on the basis of the transonic-drag-rise rule for a wing-body combination that has a wing with thickened inboard sections leads to a considerably lower drag coefficient at Mach numbers above approximately 0.90. The effect of indenting the body becomes increasingly greater with increasing Mach number and lift coefficient. As a result, above a Mach number of 0.90, the maximum lift-drag ratios are increased considerably by indenting the body. At the highest test Mach number, 1.10, indenting the body caused an increase in maximum lift-drag ratio of 22 percent.

INTRODUCTION

The results of numerous low-speed investigations and exploratory tests in the transonic speed range have indicated that increasing the aspect ratio of swept wings leads to increased maximum lift-drag ratios. Increasing the aspect ratio, however, exaggerates the structural and aeroelasticity problems. These increased structural and aeroelasticity problems can be reduced by increasing the thickness of the wing sections, but this variation leads to adverse changes in the aerodynamic characteristics which may be more important than the favorable effect of increasing the aspect ratio (ref. 1). One method of obtaining an acceptable structure and improving the aeroelastic effects without severely compromising the aerodynamic characteristics is to thicken only the inboard sections. (See refs. 2 and 3.) Improvements in the aerodynamic characteristics may also be obtained without important changes in structural weight by reducing the thicknesses of the outboard sections (ref. 1).

It has been shown in reference 4 that indenting the body of a wing-body combination with a swept, low-aspect-ratio wing can result in an essential elimination of the zero-lift drag rise for the wing near the speed of sound. The indentation used is such that the axial development of cross-sectional area normal to the airstream for the combination is the same as that for the original body alone. A similar indentation has been shown to reduce greatly the drag rise of a wing with constant thickness and higher aspect ratio (ref. 3). Thus, it was believed that a significant drag reduction could be obtained with a body indentation as specified by the transonic-drag-rise rule for a wing with high aspect ratio and thickened root sections.

In order to determine the effects of a change in aspect ratio, alterations of the spanwise variation of section thickness ratio, and a body indentation in combination with a wing with thickened inboard sections, a series of wing-body combinations have been investigated in the Langley 8-foot transonic tunnel. The results obtained at Mach numbers from 0.80 to 1.10 and angles of attack from 0° to 12° are presented herein. The Reynolds number of the investigation varied from 1.55×10^{6} to 1.65×10^{6}. Because of the necessity of expediting these data in view of the performance comparisons, the data have not been corrected for aeroelastic effects, and care should be taken in analyzing the lift and moment curves.

APPARATUS AND METHODS

Tunnel

The tests were conducted in the Langley 8-foot transonic tunnel, which is a dodecagonal, slotted-throat, single-return wind tunnel. This tunnel is designed to obtain aerodynamic data through the speed of sound without the usual effects of choking and blockage. The tunnel operates at atmospheric stagnation pressures.

Configurations

Wings.- All except one of the wings tested have 45° sweepback of the 0.25-chord line, an aspect ratio of 6, a taper ratio of 0.6, and NACA 65A-series airfoil sections parallel to the body plane of symmetry. One wing has a maximum section-thickness ratio of 6 percent from root to tip. This wing will be referred to as "the higher-aspect-ratio wing" in the discussion of aspect ratio and as "wing 6 to 6" in the discussion of effects of variation in spanwise thickness ratio. "Wing 12 to 6" has a maximum section-thickness ratio of 12 percent at the plane of symmetry, 6 percent at the midsemispan station, and 6 percent at the tip. "Wing 9 to 3" is 9 percent thick at the plane of symmetry and 3 percent thick at the tip. "Wing 12 to 3" is 12 percent thick at the plane of symmetry, 6.74 percent thick at the midsemispan station, and 3 percent thick at the tip. The absolute section thicknesses of these wings vary linearly between these stations. The plan form and spanwise variations of section thickness ratio are presented in figure 1. Another wing differing from wing 6 to 6 only in that it has an aspect ratio of 4 rather than 6 was investigated and will be referred to as "the lower-aspect-ratio wing." The plan form of one semispan of this wing is also shown in figure 1. All wings tested had an area of 1 square foot.

Wing construction.- Wings 6 to 6 and 9 to 3 were made of steel from the root sections to the tip sections. The basic structure of wing 12 to 6 was made of aluminum and was the same size and shape as wing 6 to 6. The thicker inboard sections were obtained with a plastic glove that had little or no structural strength. The basic structure of wing 12 to 3 was actually wing 9 to 3. The sections from root to semispan were thickened in a manner similar to that for wing 12 to 6. The wing with aspect ratio of 4, as was the case for wing 6 to 6, was constructed entirely of steel.

Body.- The body used in this investigation incorporated a nose $22\frac{1}{2}$ inches long and a $20\frac{1}{2}$-inch cylindrical afterbody with a diameter

of $3\frac{3}{4}$ inches. This body is shown in figure 1 and its ordinates may be found in reference 4. Wing 12 to 3 was also tested with the afterbody indented (see fig. 1) so that the cross-sectional area removed from the body at a given axial station is the same as the exposed cross-sectional area of the wing at the same station. The diameters for the axially symmetric, indented portion of the body are given in table 1. The axial area developments of the wings are given in figure 2.

All of the wings were tested on the body center line and incorporated no incidence, dihedral, twist, or camber.

Sting-support system.- The model was attached to the forward end of an enclosed strain-gage balance. At its downstream end, the balance was attached to a sting with a diameter of 3.13 inches.

Measurements and Accuracy

The average free-stream Mach number was determined to within ±0.003 from a calibration with respect to the pressure in the chamber surrounding the slotted test section.

The measured lift, drag, and pitching-moment coefficients had an accuracy of reproduction of ±0.01, ±0.001, and ±0.002, respectively.

The angle of attack of the model was measured by a pendulum-type accelerometer mounted in the nose of the model. This instrument, at any relatively constant temperature, measured angles within $\pm 0.02^\circ$. Because of the large temperature changes that occur during tests throughout the Mach number range, however, the zero of the instrument varied. Therefore, the readings of this instrument at an angle of attack of 0° was checked by a Selsyn unit, which is insensitive to temperature variation, installed at the pivot point of the mechanism that changed the angle of attack. The accuracy of this device at this condition was $\pm 0.05^\circ$. The over-all accuracy was $\pm 0.10^\circ$.

RESULTS

The basic aerodynamic characteristics - angle of attack, drag coefficient, and pitching-moment coefficient - plotted against lift coefficient for the six wing-body combinations investigated are presented in figures 3 to 6. The effects of aspect ratio on drag coefficient, drag due to lift, maximum lift-drag ratio, lift-curve slope, and static-longitudinal-stability parameter are presented in figures 7 to 11, respectively. The effects of variation in spanwise thickness ratio on these same variables are presented in figures 12 to 16, respectively.

The effect of variation in spanwise thickness ratio on the change in slope of the pitching-moment curve at pitch-up is included as figure 17. The effects of body indentation on the same variables as those shown for aspect ratio are presented in figures 18 to 22, respectively.

The drag data obtained for these tests have been corrected to values that would have been obtained had the entire base of the body been subject to free-stream static pressure.

The effects of wall-reflected disturbances on the drag results have been essentially eliminated at all Mach numbers except those near a value of 1.05. This has been accomplished by displacing the model from the tunnel center line (ref. 5), using a cylindrical afterbody, and correcting for the base-pressure variations. No results were obtained for Mach numbers near 1.05.

There are, necessarily, elasticity effects present because of the different construction materials, aspect ratios, and root-chord thicknesses employed. The data, however, have not been corrected in any way for elasticity. These effects will be considered further in the discussion of results.

In order to facilitate the presentation of the data, staggered scales have been employed in many of the figures, and care should be taken in identifying the zero axis for each curve. All references to wings in the following discussion pertain to data presented for wing-body combinations. All lift-curve slopes pertain to the linear portion of the curves at and just above a lift coefficient of zero. All pitching moments are taken about the 0.25 point of the mean aerodynamic chord. All pitching-moment-curve slopes pertain to an average slope between lift coefficients of 0 and 0.4.

DISCUSSION OF RESULTS

Effect of Aspect Ratio

<u>Drag characteristics</u>.- Results presented in figure 7 show that the drag coefficients for the higher-aspect-ratio wing are lower throughout the entire test Mach number range for lift coefficients up to 0.6.

At a lift coefficient of zero, the drag rise near a Mach number of 1.00 is reduced for the higher-aspect-ratio wing. On the basis of the results presented in reference 4, the greater part of this reduction in drag rise may be attributed to the greatly reduced maximum cross-sectional area and to the more gradual axial distribution of cross-sectional area. The axial distribution of cross-sectional area for these two wings may be found in figure 2.

The favorable effect on the drag coefficient of increasing the aspect ratio generally becomes more pronounced with increases in lift coefficient, especially at Mach numbers greater than 0.90. For example, at a lift coefficient of 0.4 and a Mach number of 1.00, the drag coefficient for the wing with aspect ratio of 6 is 25 percent lower than that for the wing with aspect ratio of 4. This may be attributed to the effect on the smaller areas of the higher-aspect-ratio wing of the large shock losses at the root sections and the severe separated flow at the tip sections (see ref. 6).

A similar study of the effects of aspect ratio has been presented in reference 7. A comparison of the drag data of the present study with those of reference 7 shows that the drag rise for the wing with aspect ratio of 4 occurs at a lower Mach number for the reference data. Results presented in reference 8 indicate that this earlier drag rise is due primarily to the different body used for the reference tests. The differences between the subcritical drag coefficients of the present tests and those of reference 7 are also believed to be primarily due to the different bodies used.

Drag due to lift.- The effect of aspect ratio on drag due to lift, presented in figure 8, shows that the higher-aspect-ratio wing has less drag due to lift throughout the test Mach number range for lift coefficients up to 0.6. Increasing the aspect ratio causes the greatest reduction in drag due to lift at the lower lift coefficients. For example, at a lift coefficient of 0.2 and a Mach number of 1.00, the reduction in drag due to lift caused by increasing the aspect ratio from 4 to 6 was 28 percent, whereas the reduction at a lift coefficient of 0.6 and a Mach number of 1.00 was only 12 percent.

The theoretical, ideal, subsonic drag for an elliptic loading is also presented in figure 8. The subsonic drags due to lift for the two wings tested are more than twice as great as the theoretical values at lift coefficients to 0.6. Comparisons of experimental results with the tangent of the angle of attack divided by the lift coefficient (see fig. 8) indicate that considerable leading-edge suction is still present at subsonic speeds. At a lift coefficient of 0.2 the curves for drag due to lift become slightly greater than the $\frac{\tan \alpha}{C_L}$ curves. This may be due to small inaccuracies in the data at these low drag coefficients.

At a lift coefficient of 0.2, the differences in drag due to lift for the two test wings are generally twice as great as the differences of the theoretical drags. At a lift coefficient of 0.4, the differences are about the same as for the theoretical drags. At a lift coefficient of 0.6, the drag due to lift of the test wings is essentially the same up to a Mach number of 0.90.

Lift-drag ratio.- The maximum lift-drag ratios for the higher-aspect-ratio wing are greater than those for the lower-aspect-ratio wing at all test Mach numbers (see fig. 9). At a Mach number of 1.00, the maximum lift-drag ratio for the wing with aspect ratio of 6 is about 30 percent greater than that for the wing with aspect ratio of 4. Also, it may be seen from the figure that rapid reduction of the lift-drag ratio, associated with compressibility effects, has been delayed from a Mach number of 0.90 to 0.96 with increase in aspect ratio.

Similar effects of aspect ratio are shown in reference 7; however, the maximum lift-drag ratios of reference 7 are higher and the increase in the divergence Mach number is only about half as great as that for the present tests.

Lift characteristics.- Results presented in figure 10 indicate that a change in aspect ratio from 4 to 6 increases the lift-curve slope throughout the Mach number range of the investigation; however, the differences are generally small.

A comparison of the aeroelastic effects on lift-curve slope for two wings aerodynamically similar to the two test wings (ref. 7) indicates that the aeroelastic effects of the present higher-aspect-ratio wing are about twice what they are for the lower-aspect-ratio wing at high subsonic speeds. For example, on the basis of the results of reference 7, taking into account the differences in materials, the lift-curve slope at a Mach number of 0.90 for the present lower-aspect-ratio wing would be reduced by 3 percent as compared with 6 percent for the higher-aspect-ratio wing. Consequently, if aeroelastic effects had been accounted for, the differences in the lift-curve slopes for the two wings presented herein at a Mach number of 0.90 would have been 4 percent instead of 1 percent.

Pitching-moment characteristics.- Results presented in figure 11 show that at Mach numbers to 0.90, the aerodynamic center of the higher-aspect-ratio wing is about 6 percent of the mean aerodynamic chord farther forward than that of the lower-aspect-ratio wing. It can be shown from the data in reference 7 that these differences are primarily due to aeroelastic effects of the wing. The curve for the lower-aspect-ratio wing breaks toward a stable condition at a Mach number of 0.90, whereas this break is delayed, for the higher-aspect-ratio wing, to a Mach number near 0.95. This delay in the break toward a stable condition may also be due to some extent to aeroelastic effects.

The slopes of the longitudinal-stability curves break at slightly lower Mach numbers for the data presented in reference 7; however, the differences in the Mach numbers for these breaks caused by increased aspect ratio are about the same as those obtained for the present tests. The lower Mach numbers shown for these breaks in the stability curves of

reference 7, as was the case for the lower drag-rise Mach number, are caused by the different bodies used for the two sets of tests.

At supersonic speeds, the aerodynamic center for the higher-aspect-ratio wing continues to shift toward a more stable position up to a Mach number of 1.08, whereas the lower-aspect-ratio wing has a constant aerodynamic-center position above a Mach number of 1.00. It is believed that if the aeroelastic effects were not present, the higher-aspect-ratio wing would be more stable than the lower-aspect-ratio wing at supersonic speeds, especially above a Mach number of 1.04.

Below a Mach number of 1.00, the unstable break in the pitching-moment curve occurs between lift coefficients of 0.5 and 0.6 for both of the wings (fig. 3(c)). At and above a Mach number of 1.00, the unstable break in the pitching-moment curve for the lower-aspect-ratio wing is at an appreciably higher lift coefficient than the break for the higher-aspect-ratio wing. A study of figure 3(c) also shows that, at subsonic speeds, the pitch-up is more severe with the lower-aspect-ratio wing; however, at supersonic speeds, the pitch-up is more severe for the higher-aspect-ratio wing.

Effects of Spanwise Variations of Section Thickness Ratio

Drag characteristics.- Figure 12 shows that, for the zero-lift condition, the wings with variation in spanwise thickness ratio have higher drag coefficients throughout the test Mach number range than does the wing with constant spanwise thickness ratio and thinner root sections. The drag-rise values for the former wings are also considerably higher than that for the latter wing. The three wings with varied spanwise thickness ratio have the same drag coefficients at zero lift throughout the test Mach number range within experimental accuracies.

At a lift coefficient of 0.2, the relationship of the drags of the wings to each other is generally the same as that for the zero-lift condition with two exceptions. At a Mach number of approximately 0.98, wing 12 to 6 (thicker root and tip sections) has the highest drag coefficient, and at supersonic Mach numbers, wing 9 to 3 (the thinnest root sections) has the least drag of the tapered-in-thickness-ratio wings, as might be expected.

At a lift coefficient of 0.4 and Mach numbers between 0.80 and 0.88, there was little difference between the low-speed values of drag coefficient for the wings with varied spanwise thickness ratio and the wing with constant spanwise thickness ratio. At the higher test Mach numbers and a lift coefficient of 0.4, the relationship of the drag coefficients of the four wings was similar to that obtained at a lift coefficient of 0.2.

At a lift coefficient of 0.6, the low-speed drag coefficients for the wings with the thinnest root sections are higher than those for the wings with thicker root sections. At the higher Mach numbers, the relationship of the drag coefficients of the wings is similar to that at the lower lift coefficients.

Drag due to lift.- Figure 13 shows that at a lift coefficient of 0.2, the drag due to lift for the thinner-root wings is generally lower up to a Mach number of 0.99. Above this Mach number, the wings with the thinner tips have the lowest drag due to lift. At lift coefficients of 0.4 and 0.6, the thinner-root wings have the highest drag due to lift at Mach numbers below about 0.90, but above this Mach number, these wings have the lowest drag due to lift.

Lift-drag characteristics.- The wings with variations in spanwise thickness ratio have considerably lower maximum lift-drag ratios throughout the entire test Mach number range than the wing with constant spanwise thickness ratio, as shown in figure 14. The Mach numbers at which the rapid decrease in maximum lift-drag ratio occur are considerably lower for the tapered-in-thickness-ratio wings than for the constant-thickness-ratio wing. Figure 14 also shows that the Mach number at which the rapid decrease in maximum lift-drag ratio occurs for these revised wings is at least partially dependent on the thickness ratio of the root and tip sections. Increased section thickness ratio leads to earlier losses. At the higher test Mach numbers, the value of maximum lift-drag ratio is also dependent upon the root and tip section thicknesses.

A comparison of figures 9 and 14 shows that, at subsonic Mach numbers, the tapered-in-thickness-ratio wings have higher maximum lift-drag ratios than does the wing with a uniform thickness of 6 percent and an aspect ratio of 4. This indicates that at subsonic speeds the favorable effect of increasing aspect ratio on maximum lift-drag ratio outweighs the adverse effect of the increases in section thickness ratios required to obtain a structure comparable to that for the lower-aspect-ratio configuration. At supersonic Mach numbers, there is little difference in the values of maximum lift-drag ratios obtained for the higher-aspect-ratio wings with tapered thickness ratio and the thinner, lower-aspect-ratio wing.

Lift characteristics.- The variation of the lift-curve slopes with Mach number for the four wings shown in figure 15 is approximately the same. Analysis of the structures of these test configurations, by use of the method of reference 7 and other computations not presented, shows that the general differences in absolute values for these slopes are primarily due to aeroelastic effects. This analysis indicates that the angular deflection at the 80-percent station for wing 9 to 3 is approximately 1/5 of that for wing 6 to 6. On the basis of this analysis, it

may be assumed that the deflections for a wing that tapers from 9 percent thick to 3 percent thick on an actual aircraft would be much less than for a 6-percent-thick wing.

Pitching-moment characteristics.- The variations of the position of the aerodynamic center with Mach number for the four wings presented in figure 16 are approximately the same. Computations indicate that the differences in the position of the aerodynamic center for these four wings are attributable to aeroelastic effects, as were the differences in the lift characteristics.

The severities of the pitch-ups for the four wings tested for variation in spanwise thickness are shown on figure 17. At Mach numbers to approximately 0.94, the wings with the thinnest tip sections have the most severe pitch-ups, but at higher Mach numbers to the highest test Mach number, the wings with the thinnest root sections have the most severe pitch-ups.

Effect of Body Indentation

Drag characteristics.- The effect of body indentation on drag coefficient at constant lift coefficient with wing 12 to 3 is shown in figure 18. It may be noted in this figure that at zero lift and a Mach number of 1.00, the theoretical design condition for the indented body, the indentation eliminates only about 50 percent of the drag rise, whereas for the wing with aspect ratio of 4 in reference 4, the drag rise was virtually eliminated. The incomplete effect of the indentation is similar to that noted in reference 9 for an indented body with an unswept, highly tapered wing, and is believed to be caused by an excessively rapid area development for the body which led to a thickening or separation of the boundary layer in the region of the indentation. The absolute effect of the indented body increases markedly with Mach number to the highest test value, whereas for the wing with aspect ratio of 4 in reference 4 the effect decreased with Mach number.

A particularly important point to be noted in figure 18 is the effect of body indentation on the drag coefficient at lifting conditions. At a Mach number of 1.00 and a lift coefficient of 0.4, the decrease in drag coefficient caused by indenting the body was about $2\frac{1}{2}$ times greater than the reduction in drag coefficient noted for the zero-lift condition. This favorable effect increases with increase in Mach number to the highest test value. At a lift coefficient of 0.6 this favorable effect is less than at a lift coefficient of 0.4, for Mach numbers greater than 1.00.

At the lower Mach numbers and a lift coefficient of 0.6, indenting the body increases the drag by as much as 18 percent. This effect is probably due to a separation of the flow about the indentation.

Drag due to lift.- At low speeds, the drag due to lift with the indented body is generally higher than with the cylindrical body (see fig. 19). The drag due to lift is generally less with the indented body than with the cylindrical body at Mach numbers above 0.95. At a lift coefficient of 0.4, which is near the condition for maximum lift-drag ratio, and a Mach number of 1.00, indenting the body decreased the drag due to lift by almost 16 percent.

Lift-drag ratio.- Up to a Mach number of 0.90, there is no difference between the values of maximum lift-drag ratio for wing 12 to 3 with the cylindrical and with the indented body (see fig. 20). At Mach numbers greater than 0.90, the wing in combination with the indented body has maximum lift-drag ratios that are considerably higher than those obtained with the cylindrical body. This difference amounts to about 17 percent at a Mach number of 1.00. This effect increases with Mach number so that, at the highest test Mach number, the maximum lift-drag ratio for the wing with the indented body is 22 percent greater than that for the cylindrical body. The indentation also delays the Mach number at which rapid reduction in lift-drag ratio occurs from 0.90 to 0.95.

Lift characteristics.- Figure 21 shows that, at Mach numbers to approximately 0.95, the lift-curve slopes for wing 12 to 3 in combination with the indented body are little different from those for this wing with the cylindrical body. At Mach numbers above 0.95, the lift-curve slopes for the indented body become greater, and at Mach numbers between 1.00 and 1.10, the wing with the indented body has lift-curve slopes that are approximately 10 percent higher than those obtained with the cylindrical body.

Pitching-moment characteristics.- The rate of change of the static-longitudinal-stability parameter dC_m/dC_L with Mach number near the speed of sound for the indented-body configuration is more gradual than that for the cylindrical-body configuration (fig. 22). Figure 6(c) shows that indenting the body has little effect on the lift coefficient at which the unstable break in pitching moment occurs. The severity of the pitch-up is also little affected by body indentation.

CONCLUSIONS

Tests have been performed to determine the effects of aspect ratio, spanwise variation of thickness ratio, and a body indentation on the

aerodynamic characteristics of a 45° sweptback wing-body combination. The results of these tests lead to the following conclusions:

1. Increasing the aspect ratio from 4 to 6 leads to reduced drag coefficients, especially at Mach numbers above 0.90 and for lifting conditions. These effects cause considerable increases in the maximum lift-drag ratios. Increasing the aspect ratio also delays the Mach number at which the rapid reduction in maximum lift-drag ratio occurs due to compressibility effects.

2. Thickened inboard sections, in general, lead to higher drag coefficients, especially at supersonic Mach numbers. They also lead to lower lift-drag ratios throughout the transonic Mach number range, as well as earlier rapid reductions in maximum lift-drag ratios. Thinning the tip sections improves the maximum lift-drag ratios slightly.

3. At subsonic speeds, the favorable effect on drag characteristics of increasing the aspect ratio more than offsets any adverse effects of moderately thickening the inboard sections of a wing, as required to obtain the desired structural strength with this higher aspect ratio. At supersonic test Mach numbers, the maximum lift-drag ratios for a wing with aspect ratio of 6 and moderately thickened inboard sections are about the same as those obtained for a wing with aspect ratio of 4.

4. Indenting the body leads to considerably lower drag coefficients at Mach numbers above approximately 0.90. The effect of indenting the body becomes increasingly greater with increasing Mach number and lift coefficient. As a result, above a Mach number of 0.90 the maximum lift-drag ratios are increased considerably with increasing Mach number by indenting the body. At the highest test Mach number, 1.10, indenting the body caused an increase in maximum lift-drag ratio of 22 percent.

5. Aspect ratio, variations in spanwise thickness ratio, and body indentations have only small effects on the variation of lift-curve slope and aerodynamic-center position with Mach number.

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TABLE I

ORDINATES FOR INDENTED PORTIONS OF THE BODY

Axial distance from leading edge of wing, in.	Fuselage diameter, in.
1.267	3.750
2.000	3.740
2.500	3.584
3.000	3.426
3.500	3.300
4.000	3.184
4.500	3.080
5.000	2.998
5.500	2.950
6.000	2.938
6.500	2.938
7.000	2.970
7.500	3.060
8.000	3.146
8.500	3.210
9.000	3.260
9.500	3.300
10.000	3.332
10.500	3.360
11.000	3.390
11.500	3.416
12.000	3.444
12.500	3.466
13.000	3.496
13.500	3.520
14.000	3.544
14.500	3.570
15.000	3.596
15.500	3.620
16.000	3.642
16.500	3.666
17.000	3.690
17.500	3.710
18.000	3.722
18.500	3.738
19.000	3.748
19.500	3.750

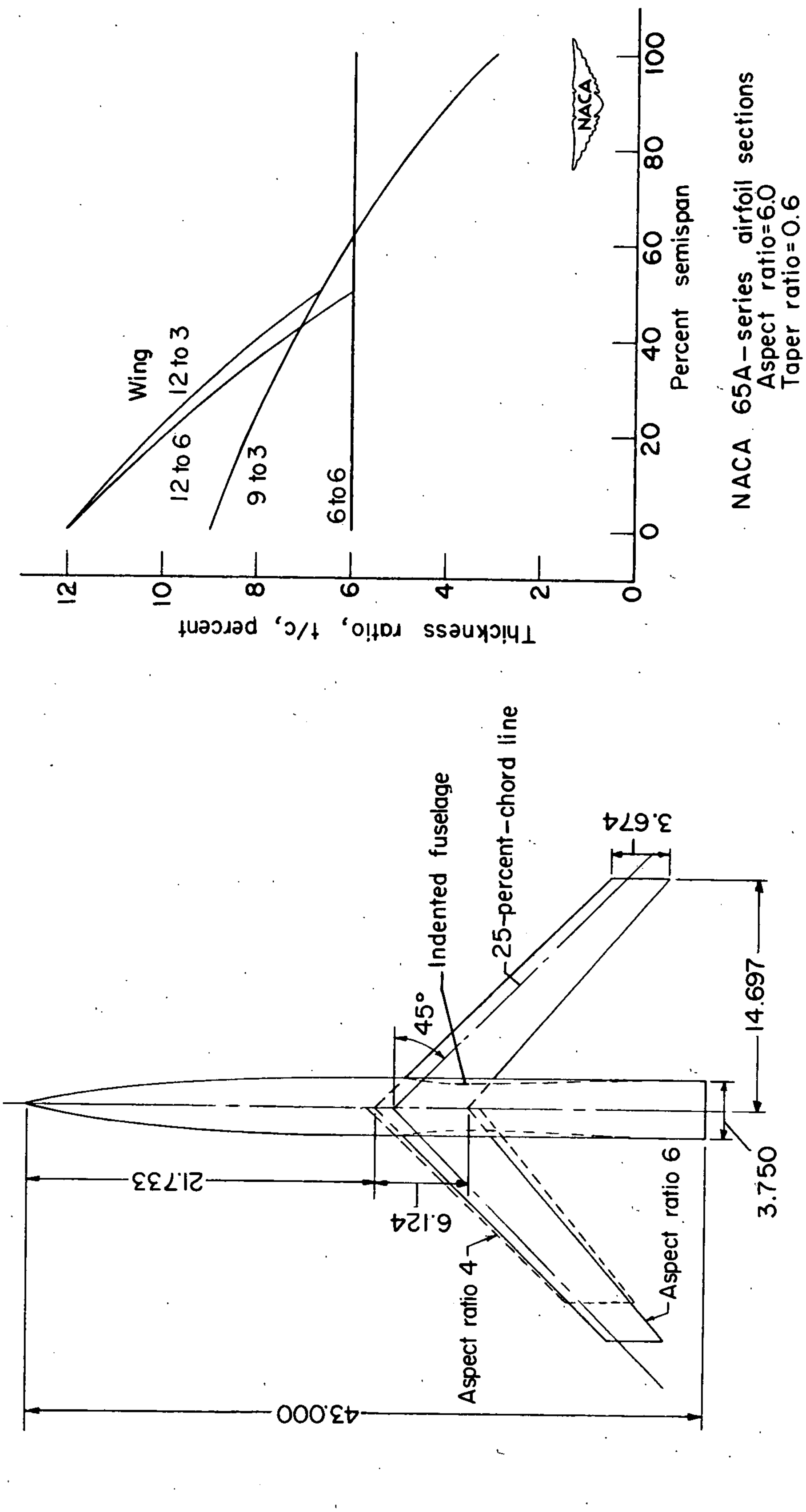


Figure 1.- Model dimensions in inches.

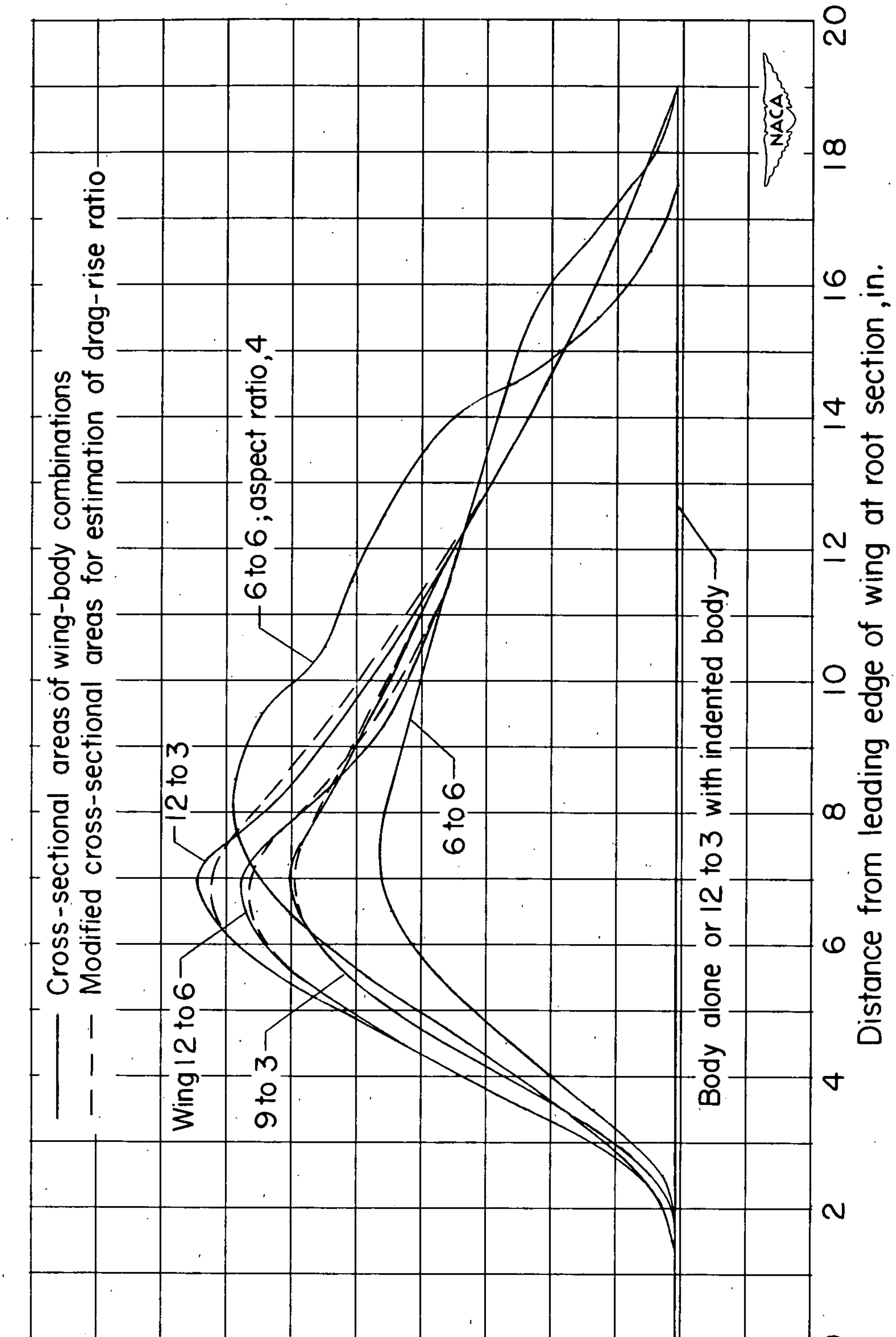
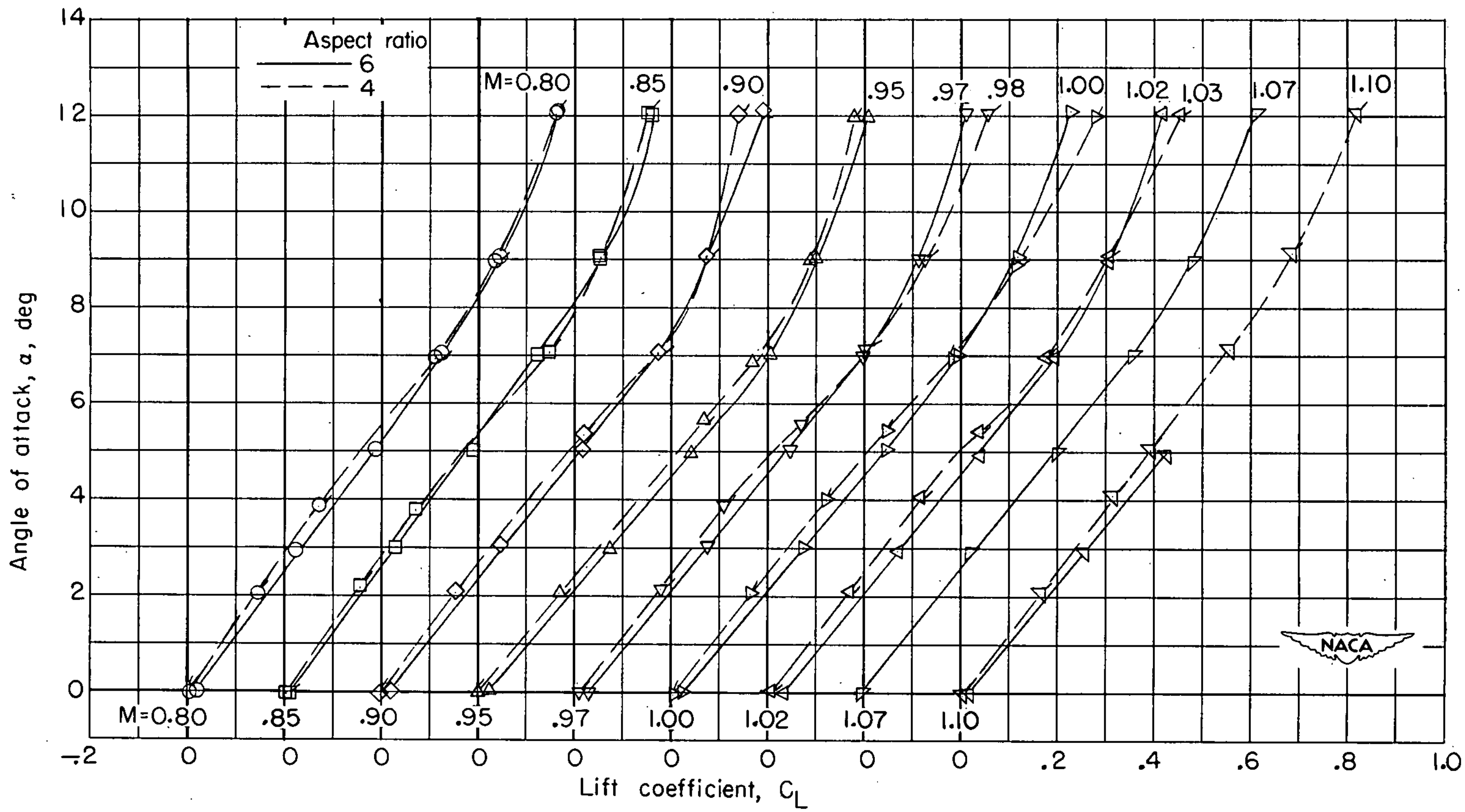
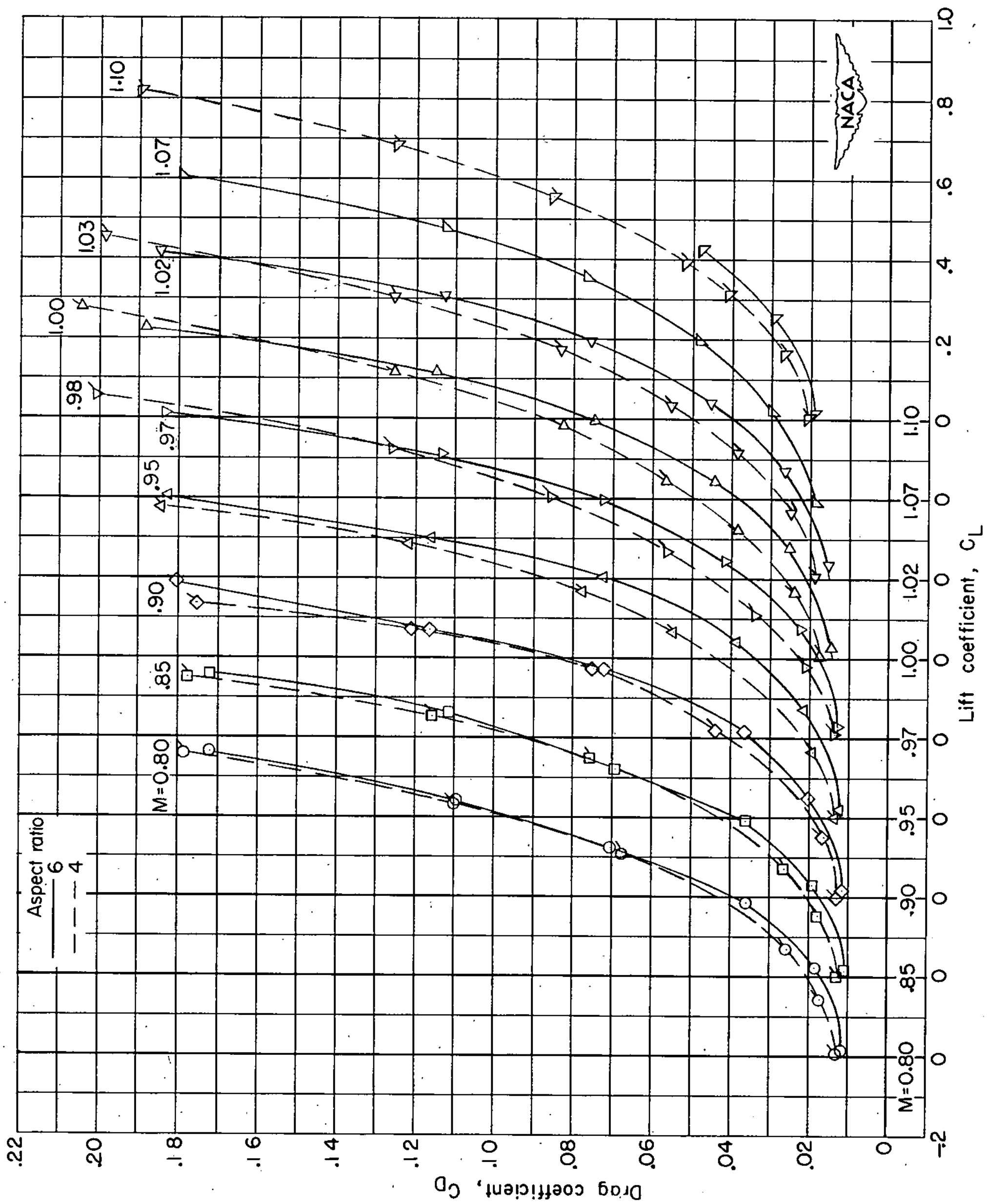


Figure 2.- Axial area development of test wings.



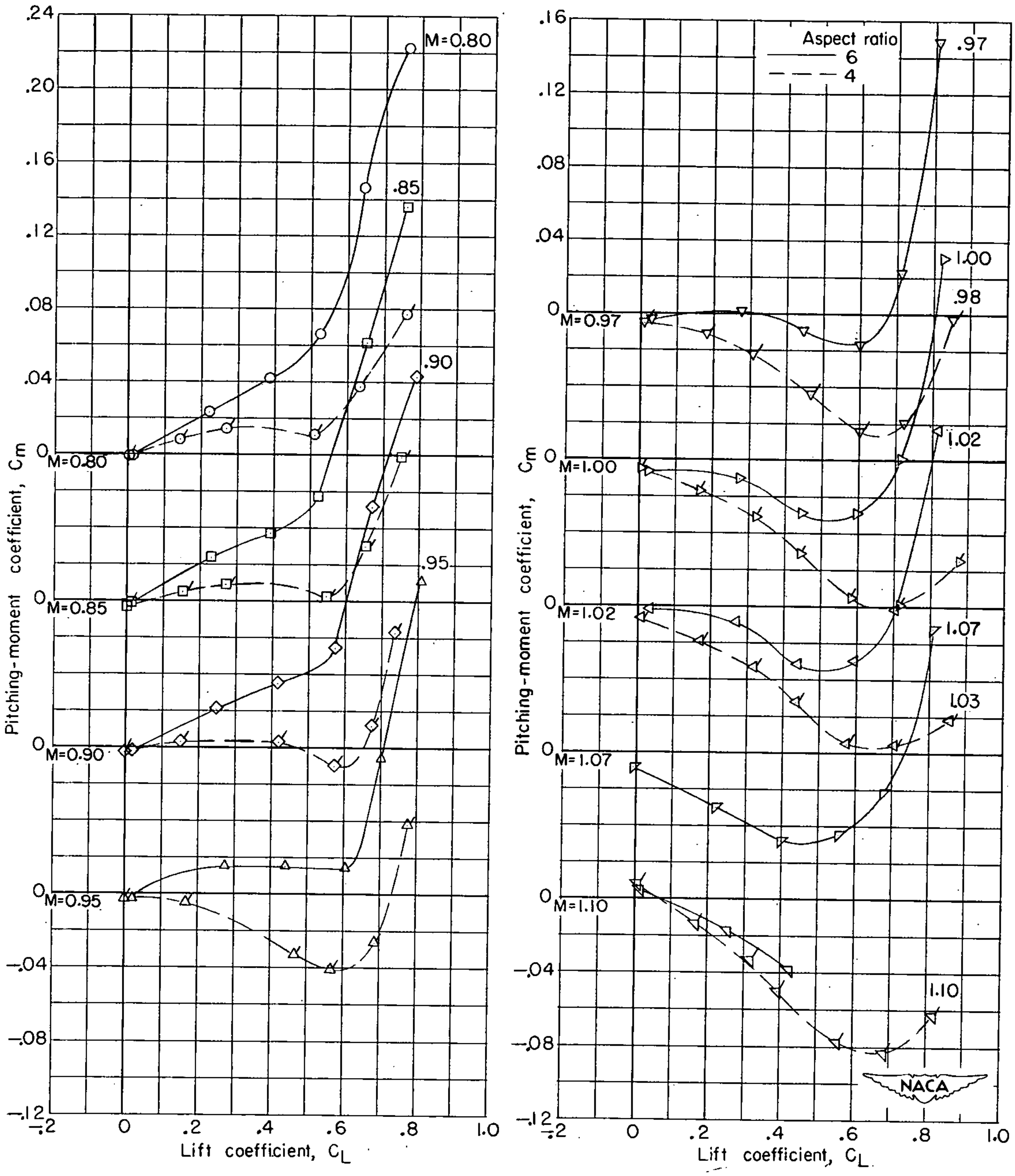
(a) Angle of attack.

Figure 3.- Variation with lift coefficient of the aerodynamic characteristics of two wing-body combinations with NACA 65A-006 airfoil sections. Sweepback, 45°; taper ratio, 0.6; aspect ratios, 4.0 and 6.0. Plain symbols indicate aspect ratio of 6; flagged symbols indicate aspect ratio of 4.



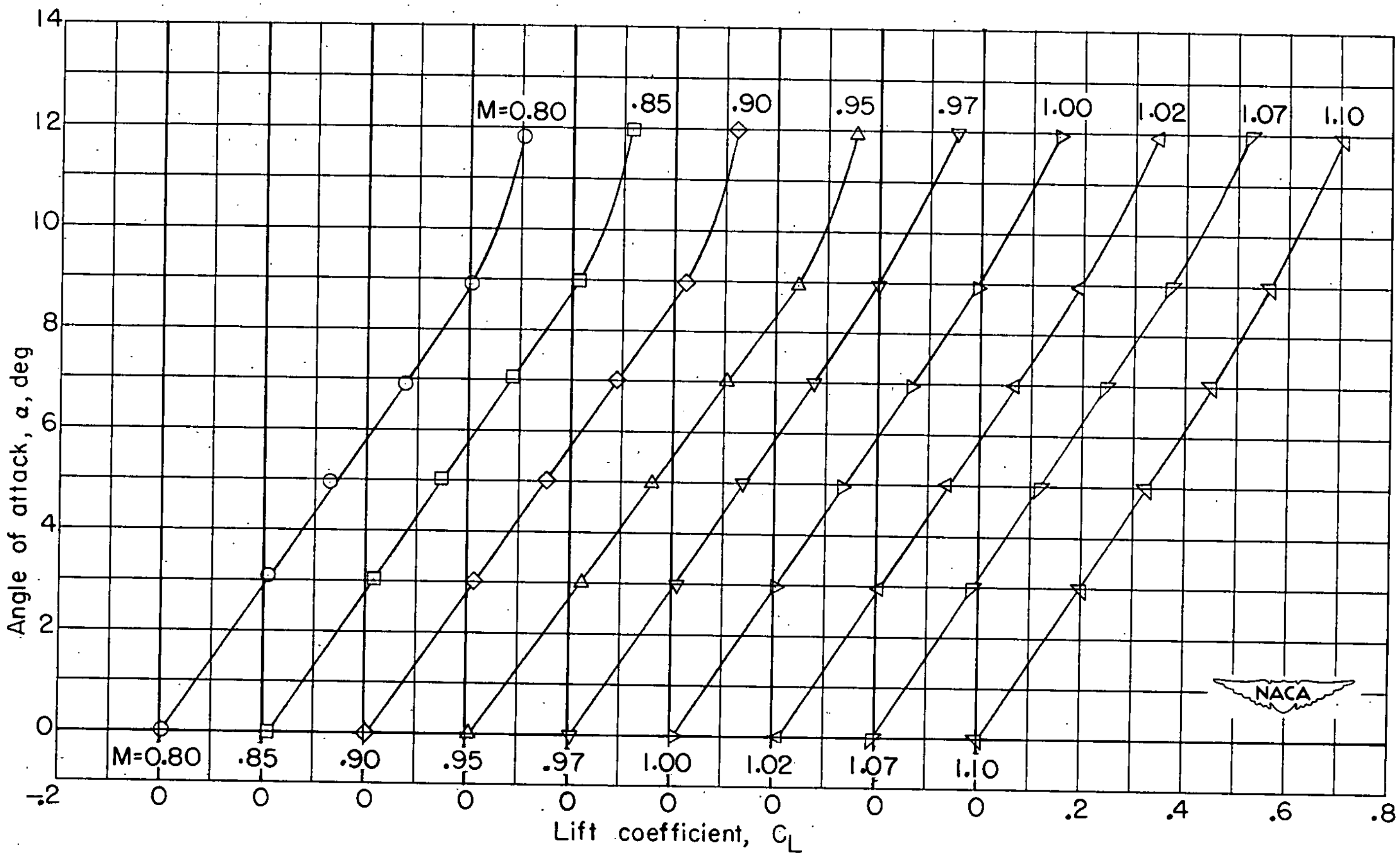
(b) Drag coefficient.

Figure 3.- Continued.



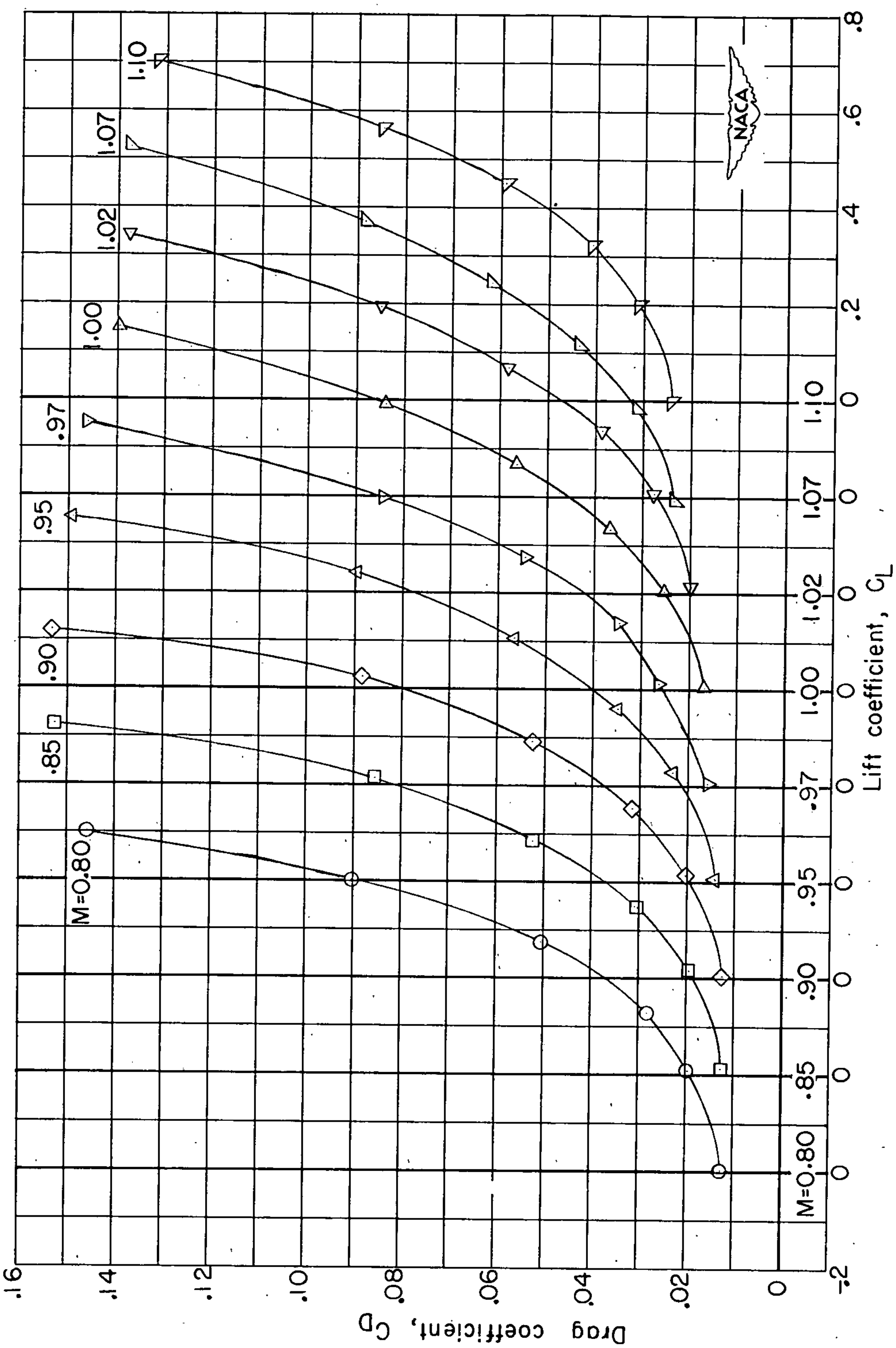
(c) Pitching-moment coefficient.

Figure 3.- Concluded.



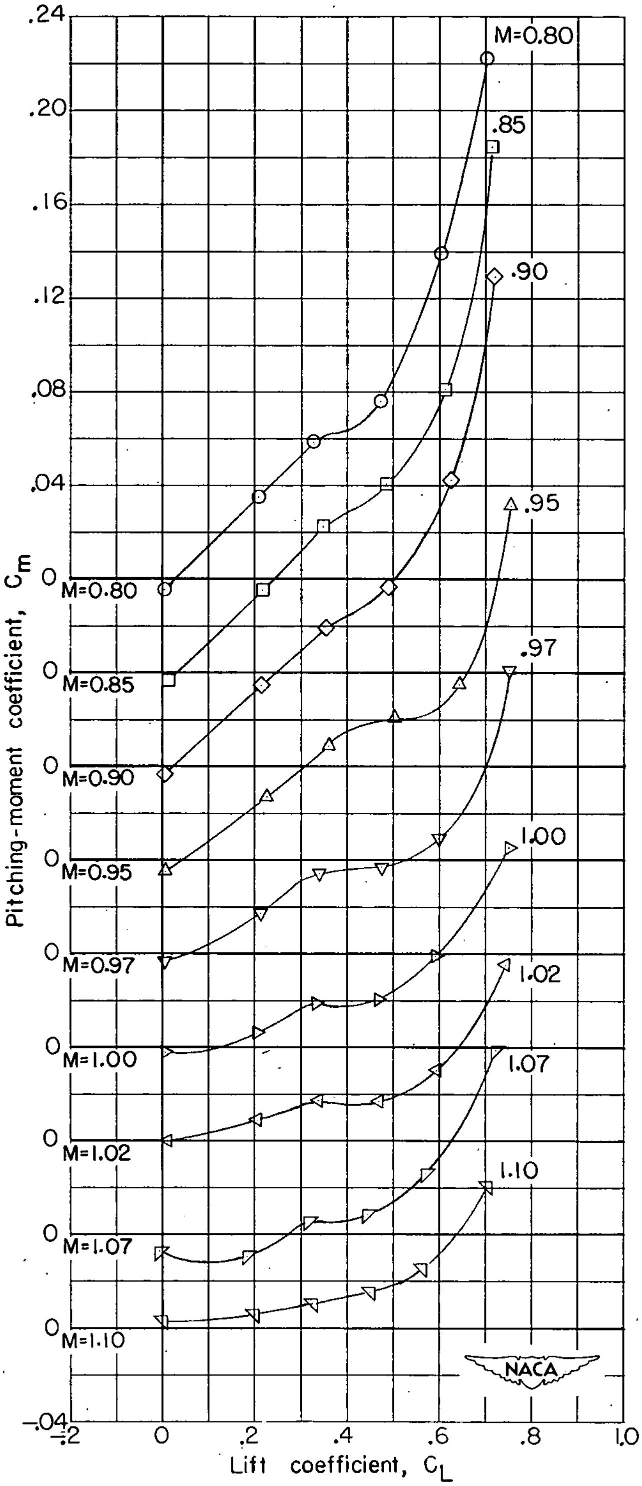
(a) Angle of attack.

Figure 4.- Variation with lift coefficient of the aerodynamic characteristics of a wing-body combination with NACA 65A-series airfoil sections of 12-percent thickness at the plane of symmetry tapered to 6 percent at the semispan and 6 percent at the tip. Sweepback, 45°; taper ratio, 0.6; aspect ratio, 6.0.



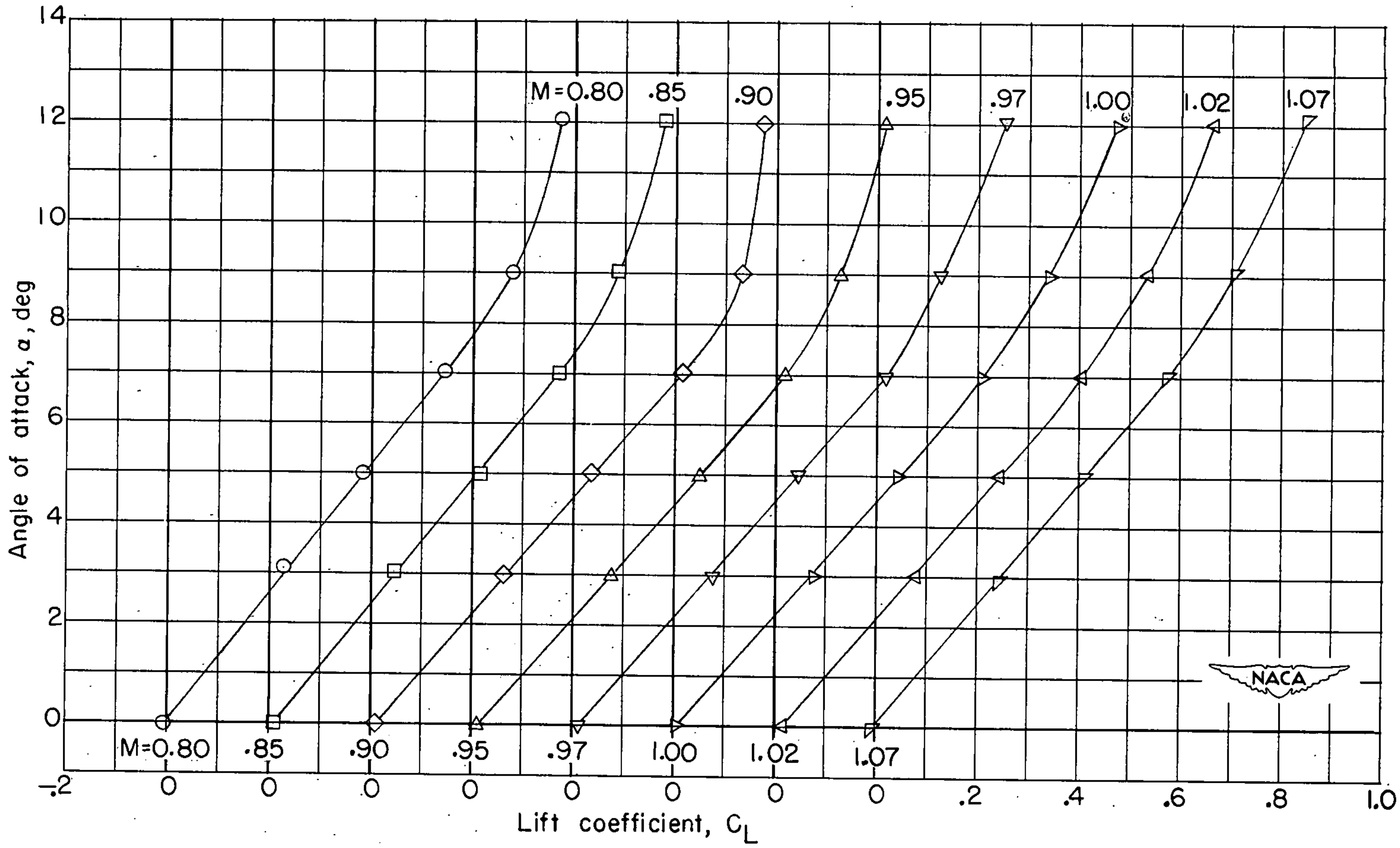
(b) Drag coefficient.

Figure 4.- Continued.



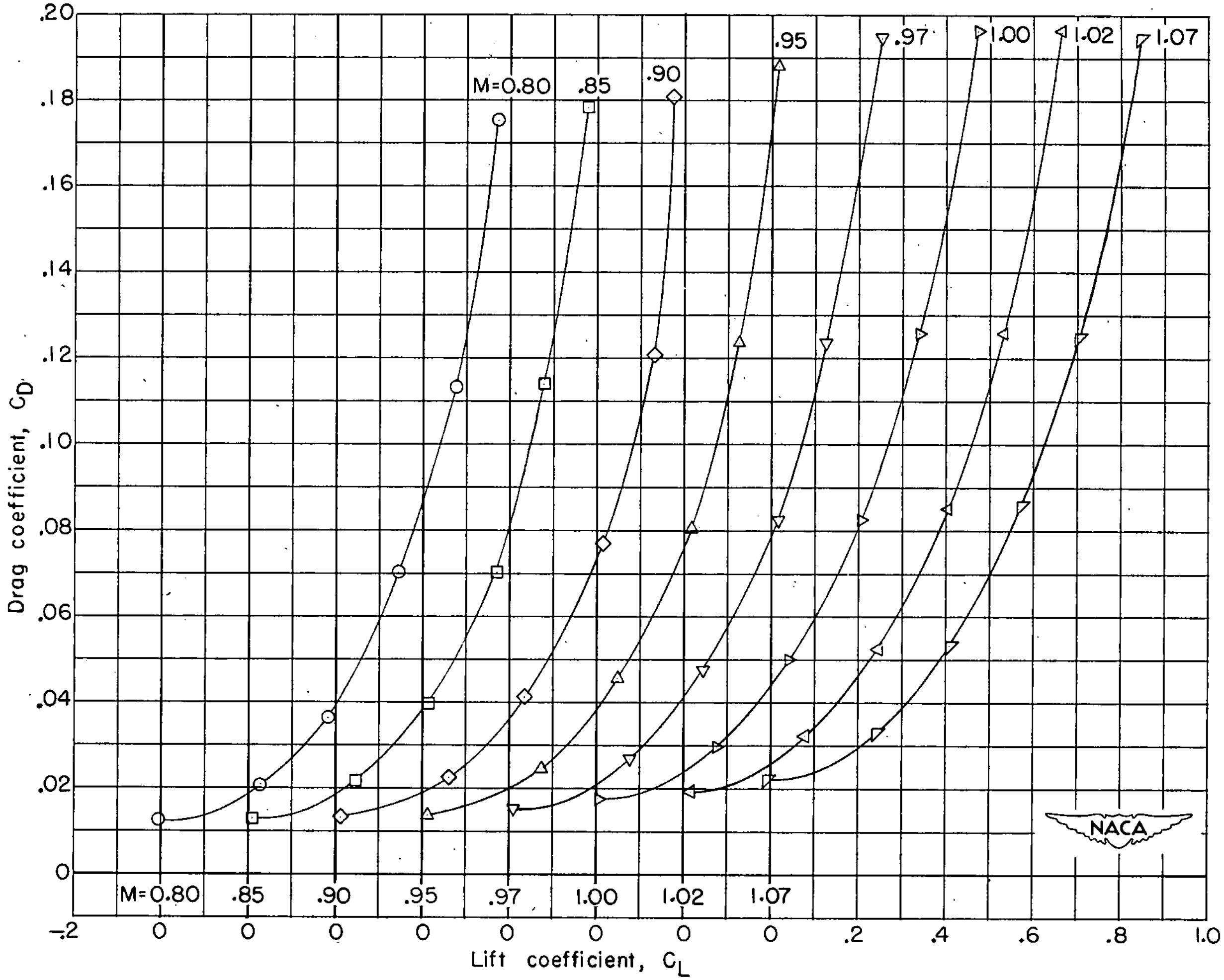
(c) Pitching-moment coefficient.

Figure 4.- Concluded.



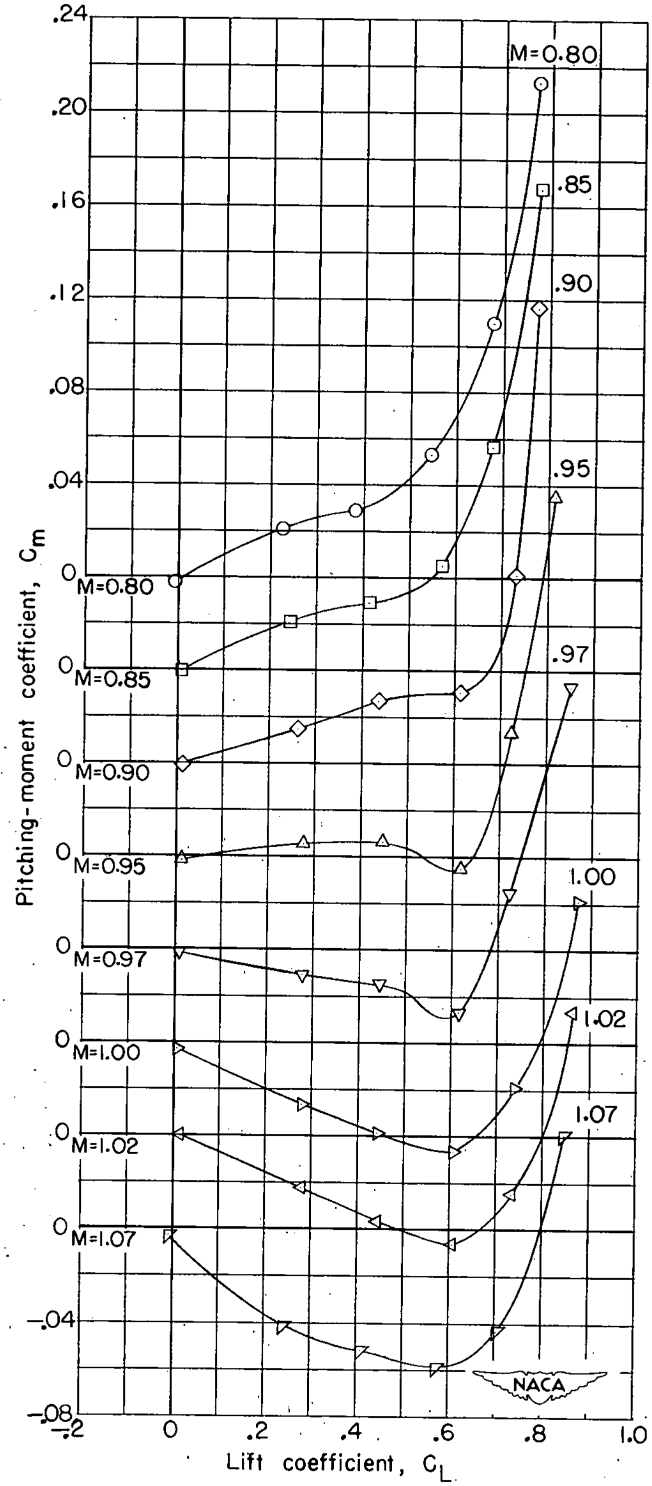
(a) Angle of attack.

Figure 5.- Variation with lift coefficient of the aerodynamic characteristics of a wing-body combination with NACA 65A-series airfoil sections of 9-percent thickness at the plane of symmetry tapered to 3 percent at the tip. Sweepback, 45°; taper ratio, 0.6; aspect ratio, 6.0.



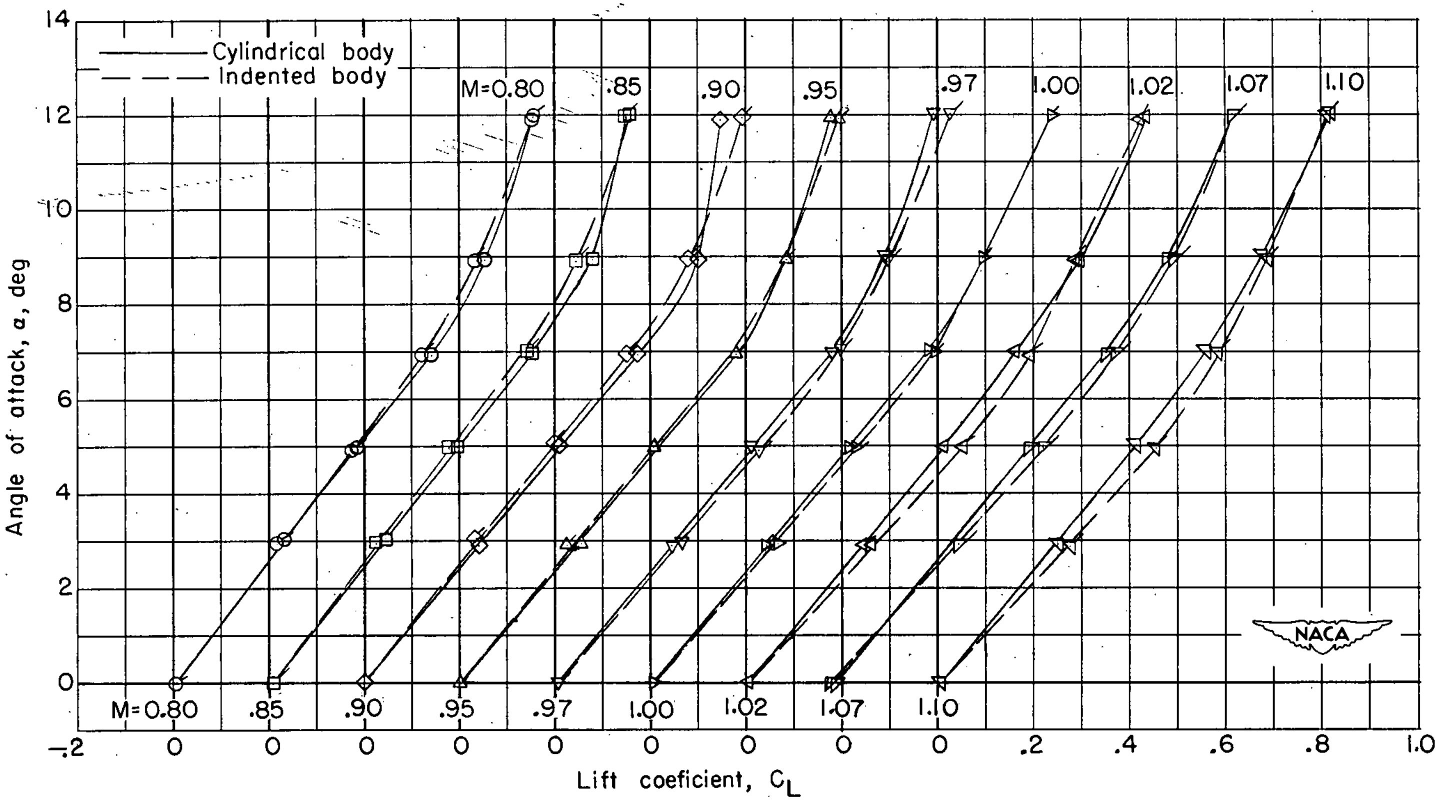
(b) Drag coefficient.

Figure 5.- Continued.



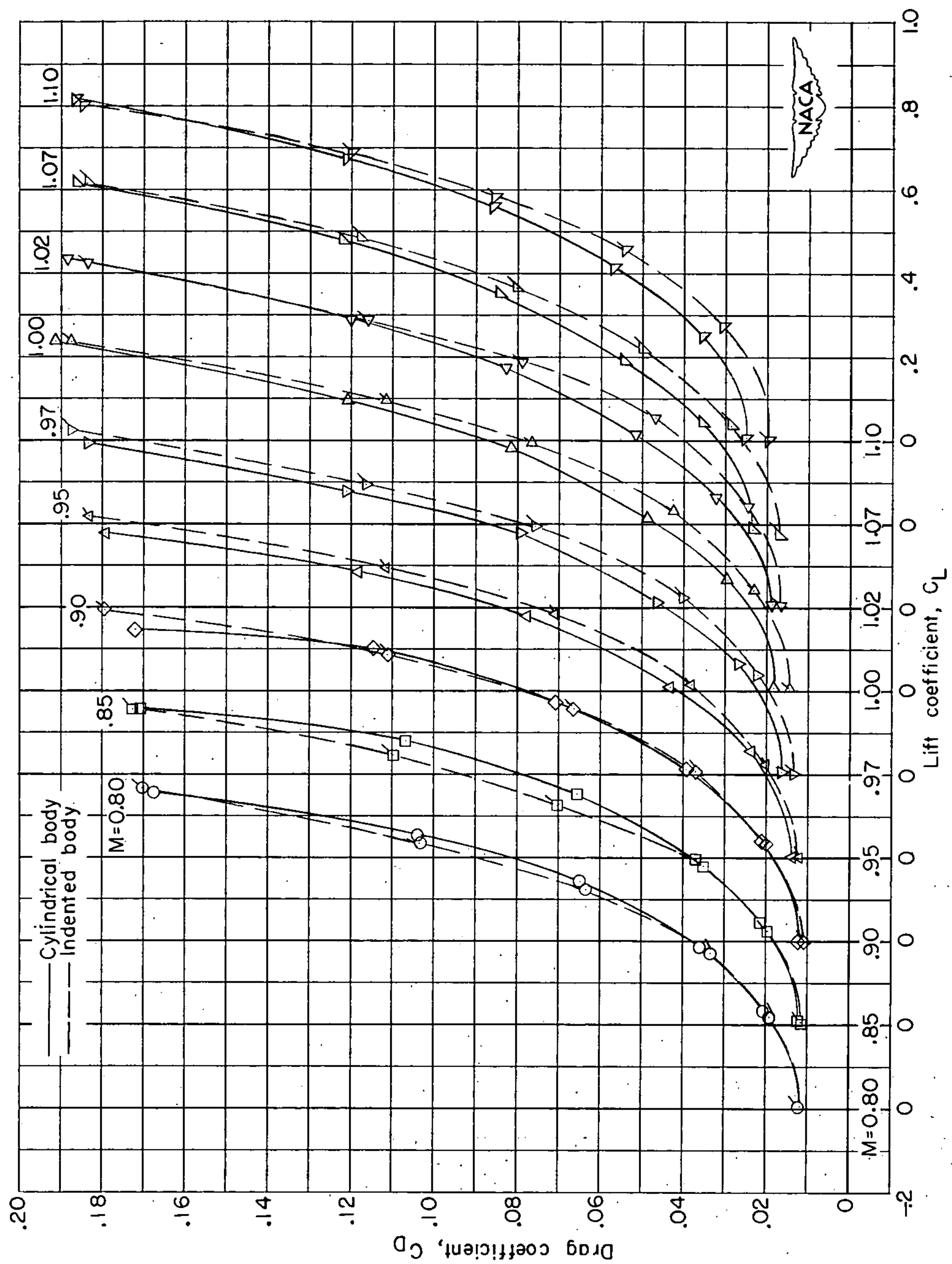
(c) Pitching-moment coefficient.

Figure 5.- Concluded.



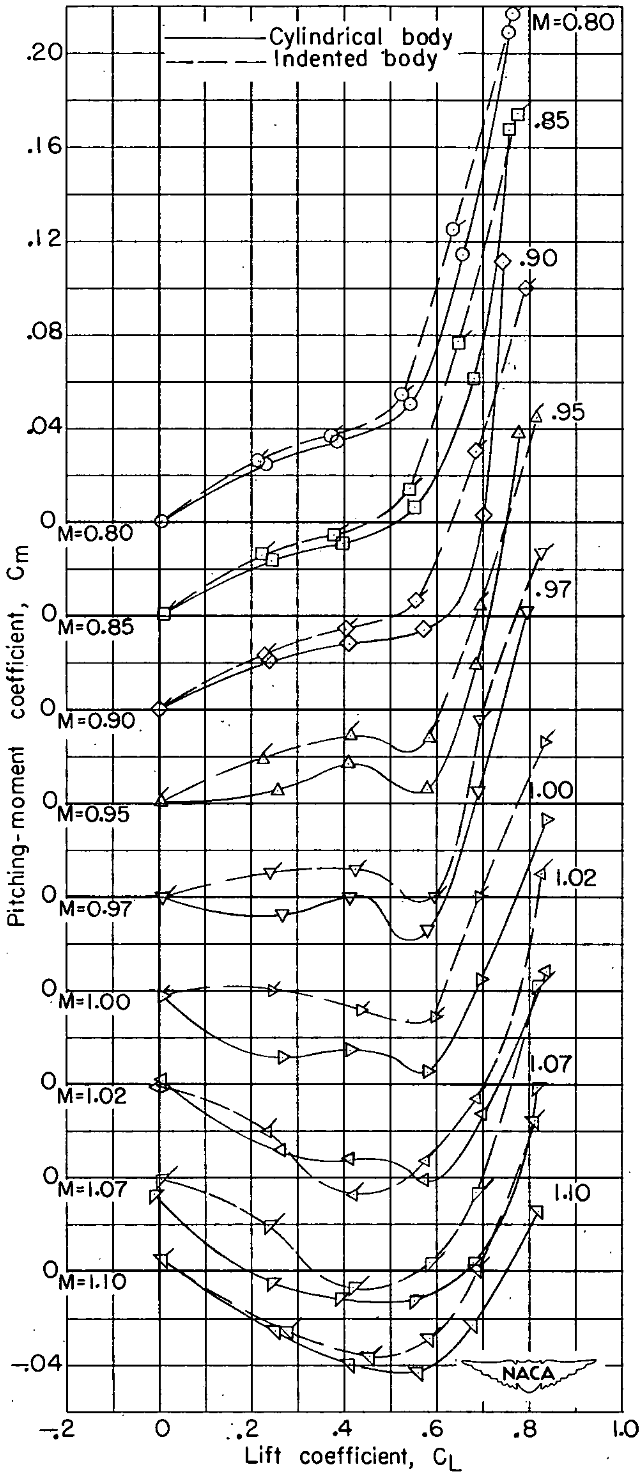
(a) Angle of attack.

Figure 6.- Variation with lift coefficient of the aerodynamic characteristics of two wing-body combinations with NACA 65A-series airfoil sections of 12-percent thickness at the plane of symmetry tapered to 6.75 percent at the semispan and 3 percent at the tip. Sweepback, 45°; taper ratio, 0.6; aspect ratio, 6.0; body, cylindrical and indented. Plain symbols indicate data for cylindrical body; flagged symbols indicate data for indented body.



(b) Drag coefficient.

Figure 6.- Continued.



(c) Pitching-moment coefficient.

Figure 6.- Concluded.

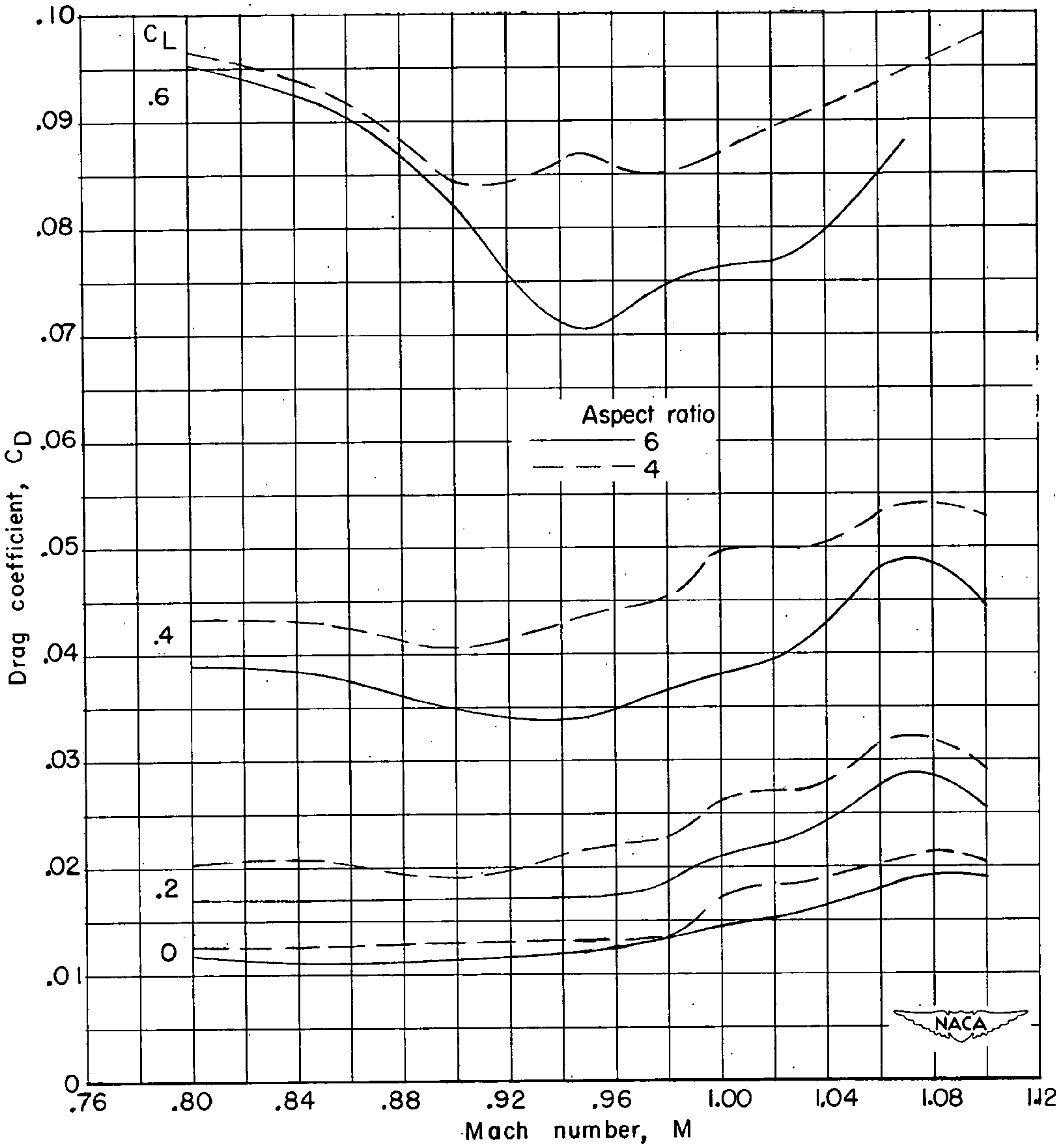


Figure 7.- Effect of aspect ratio on the variation of drag coefficient with Mach number for several values of lift coefficient.

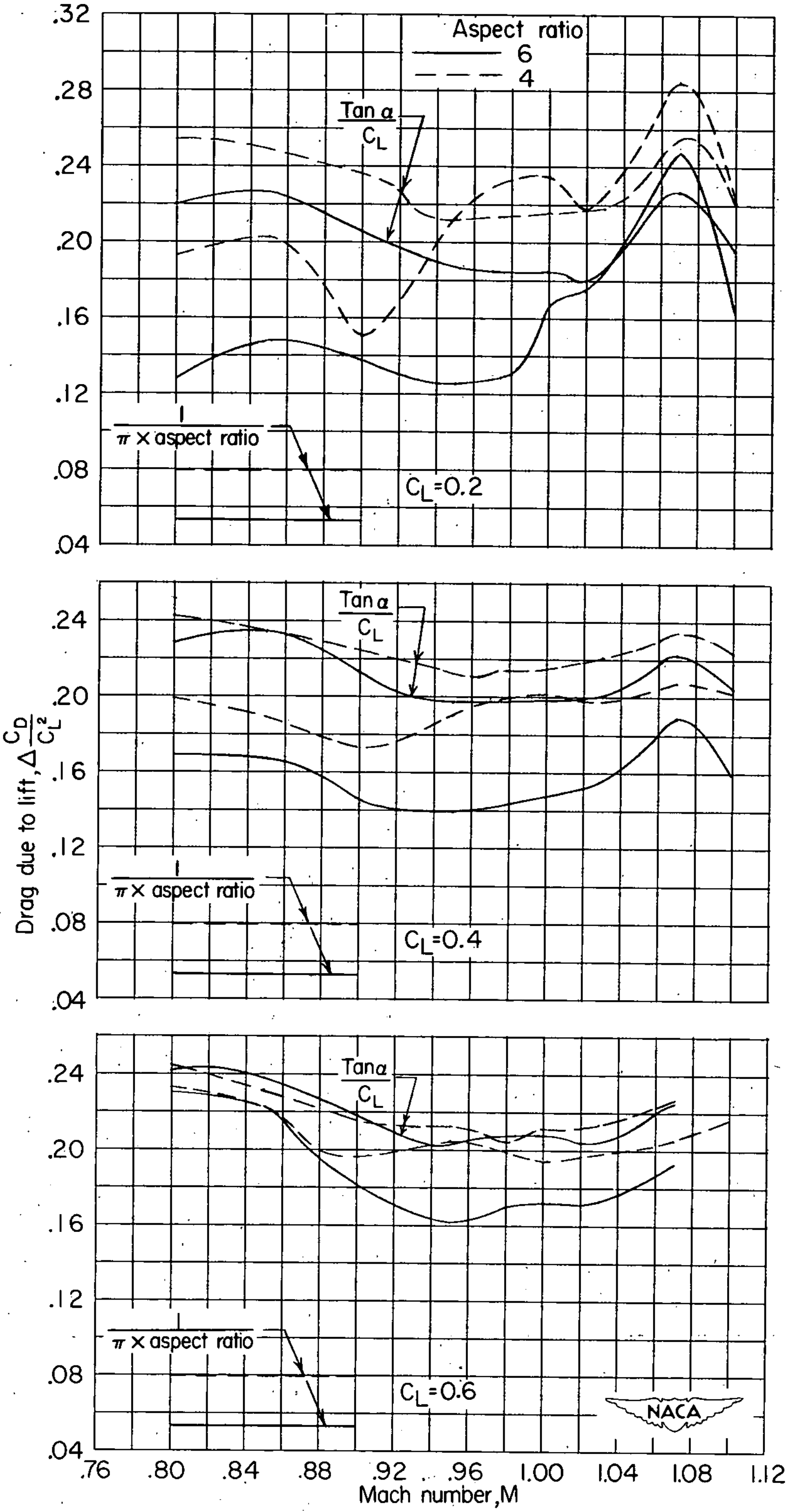


Figure 8.- Effect of aspect ratio on drag due to lift.

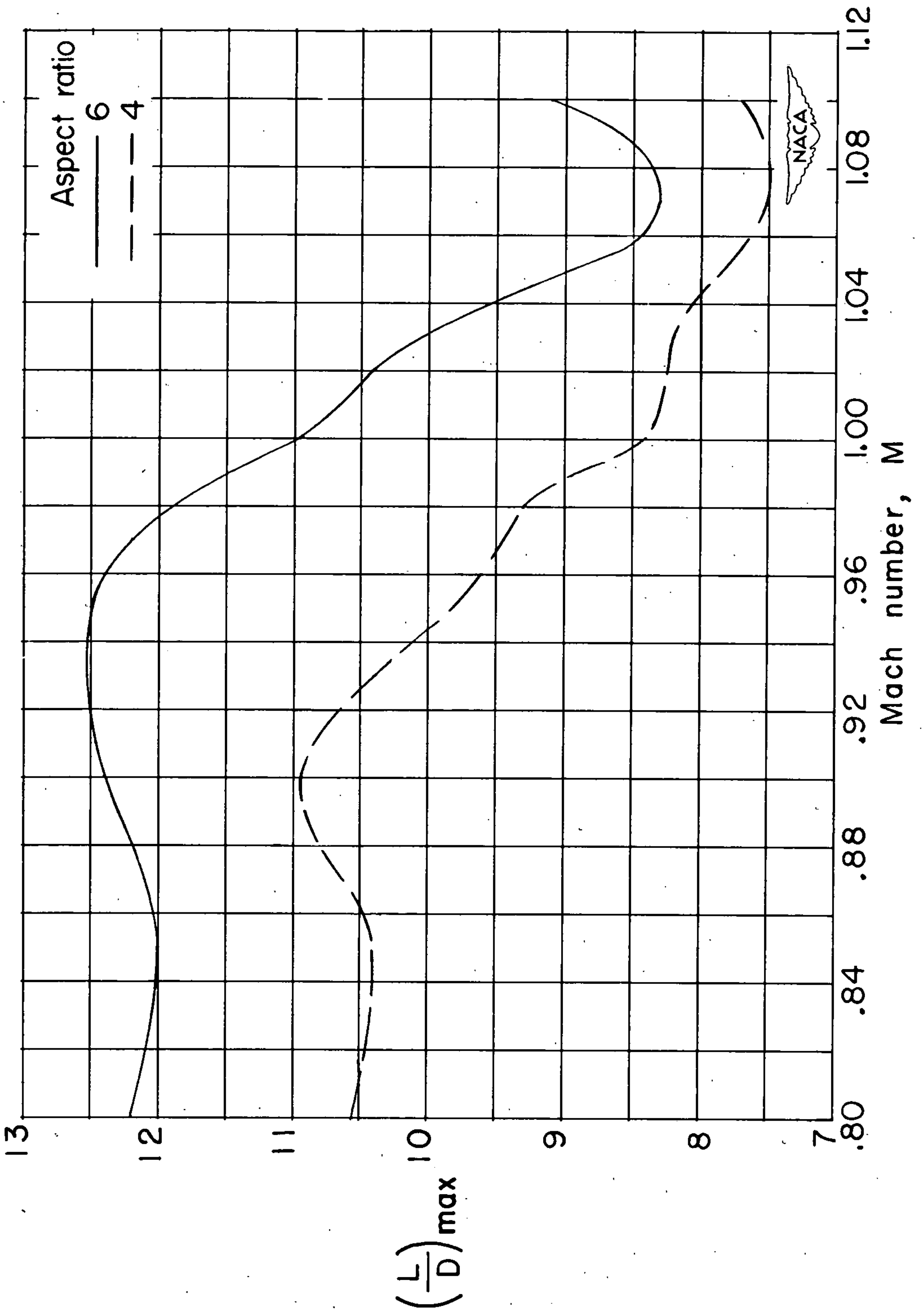


Figure 9.- Effect of aspect ratio on the variation of maximum lift-drag ratio with Mach number.

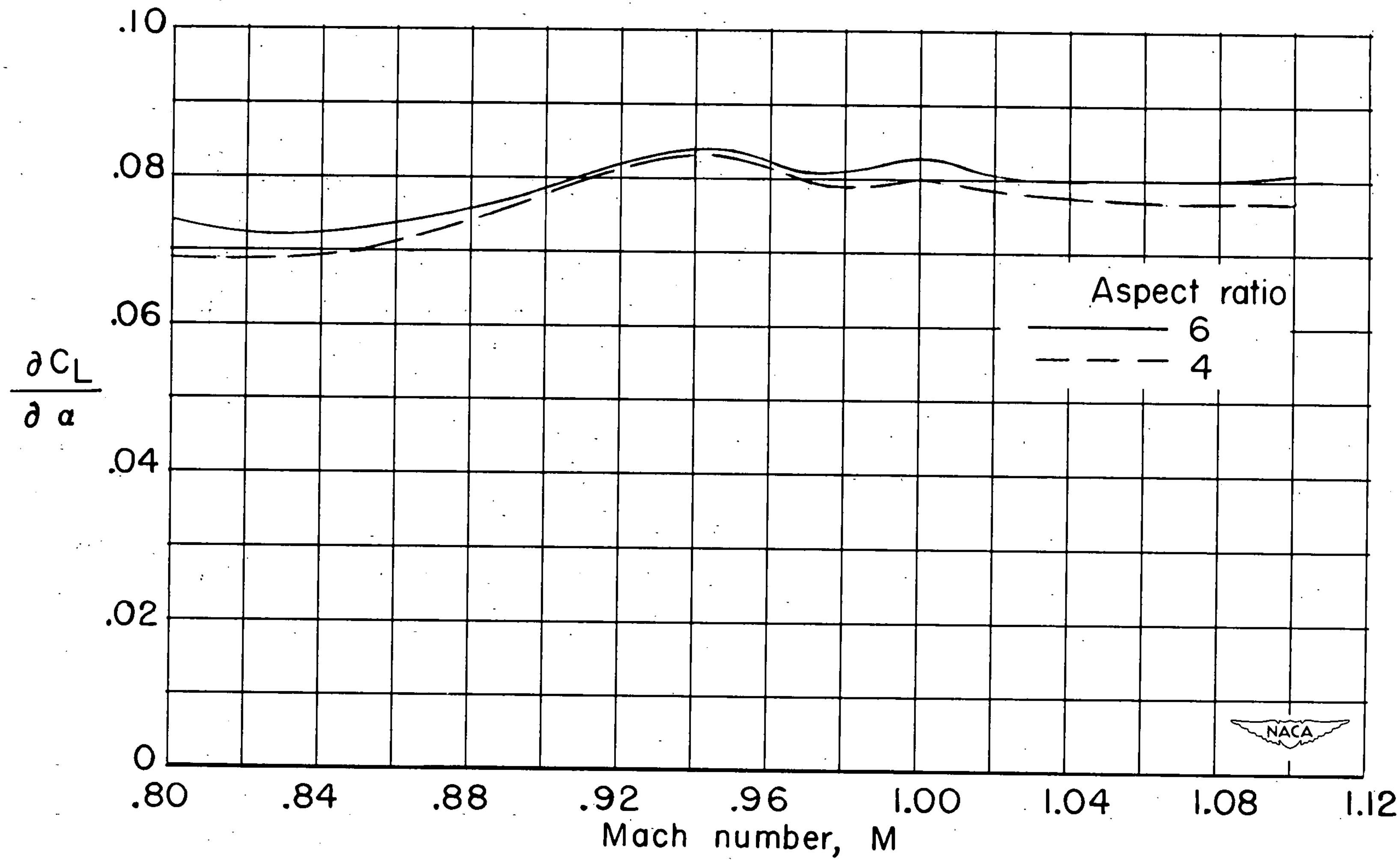


Figure 10.- Effect of aspect ratio on the variation of lift-curve slope with Mach number.

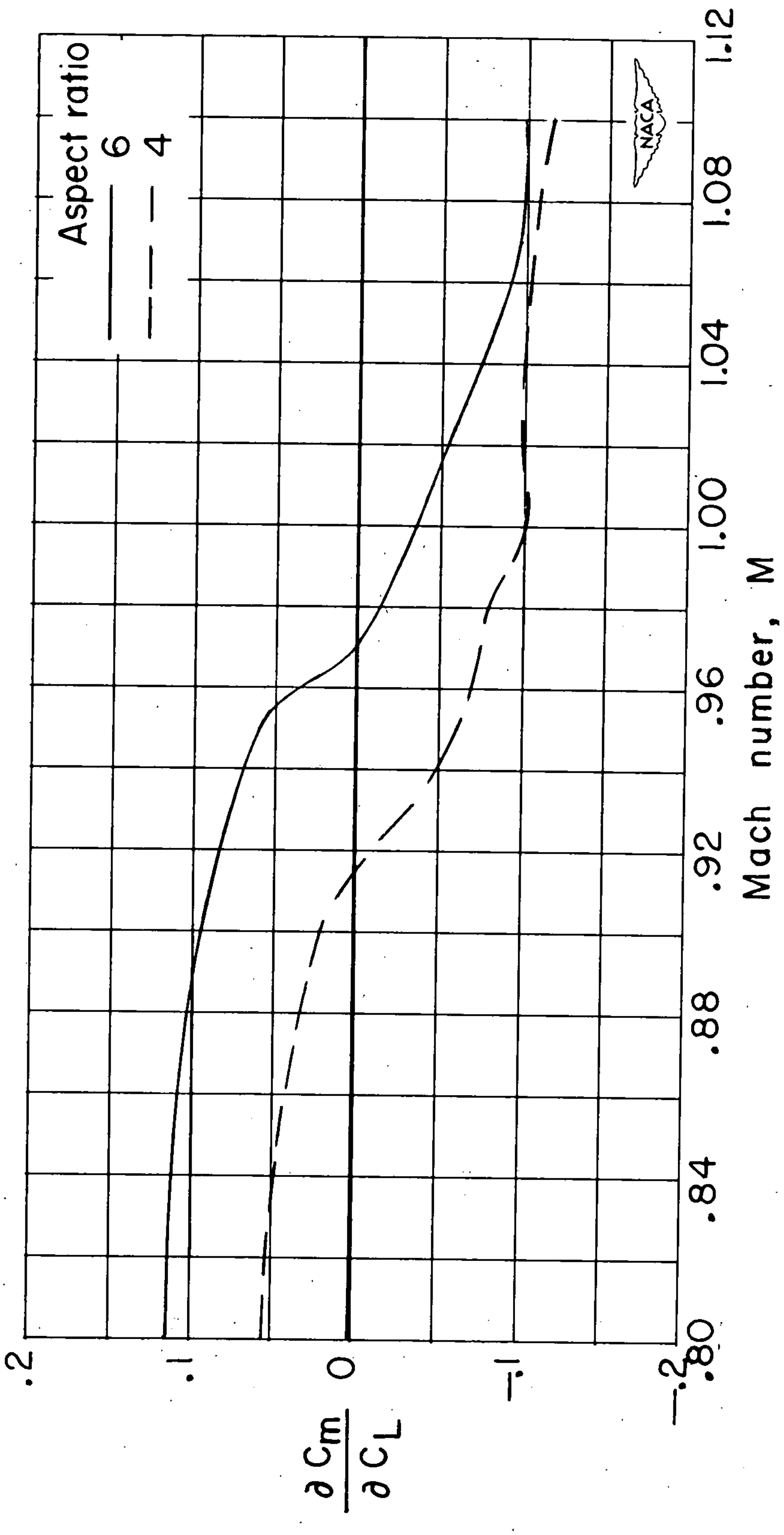


Figure 11.- Effect of aspect ratio on the variation of the static-longitudinal-stability parameter with Mach number.

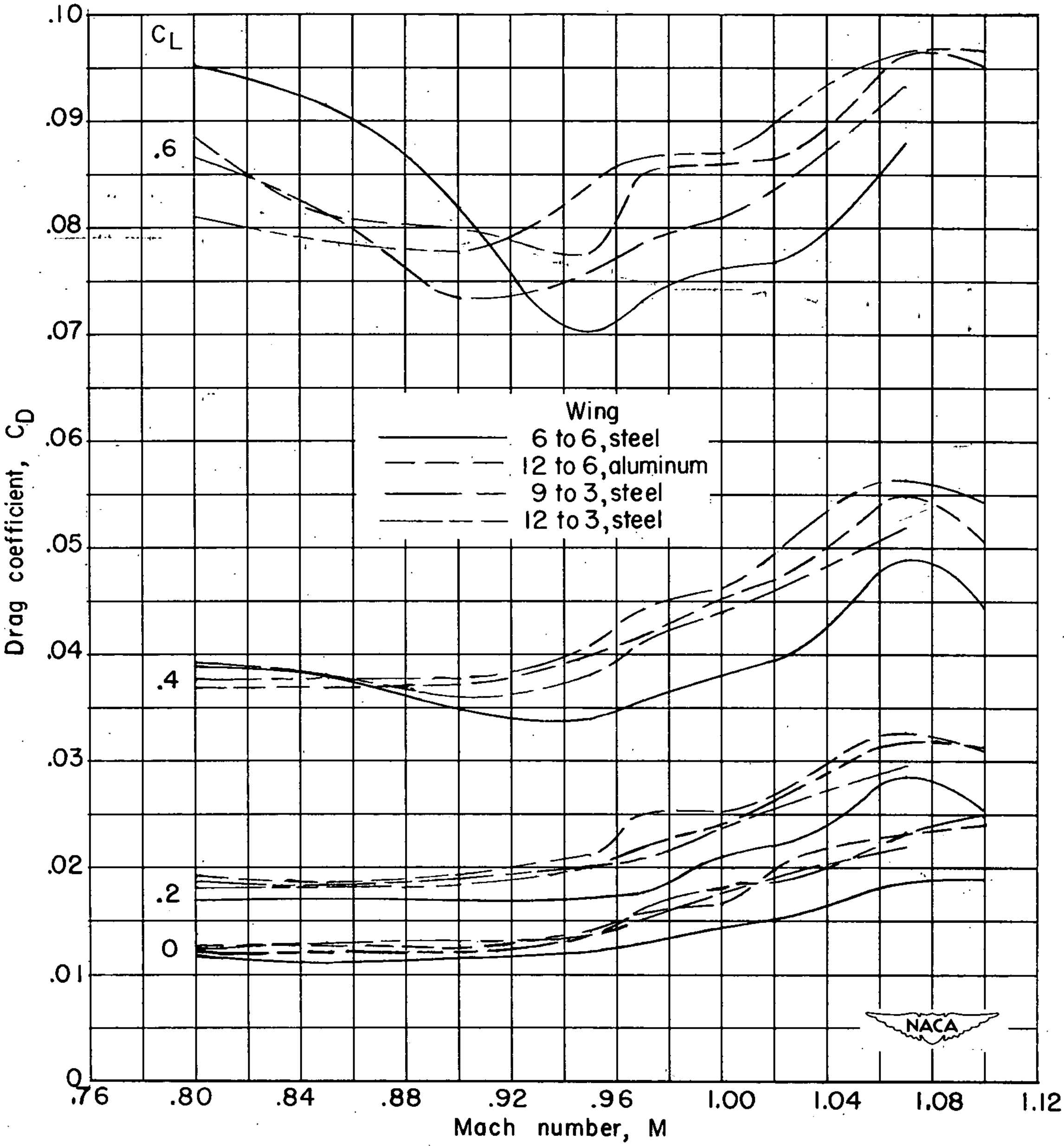


Figure 12.- Effect of spanwise taper in thickness ratio on the variation of drag coefficient with Mach number for several lift coefficients.

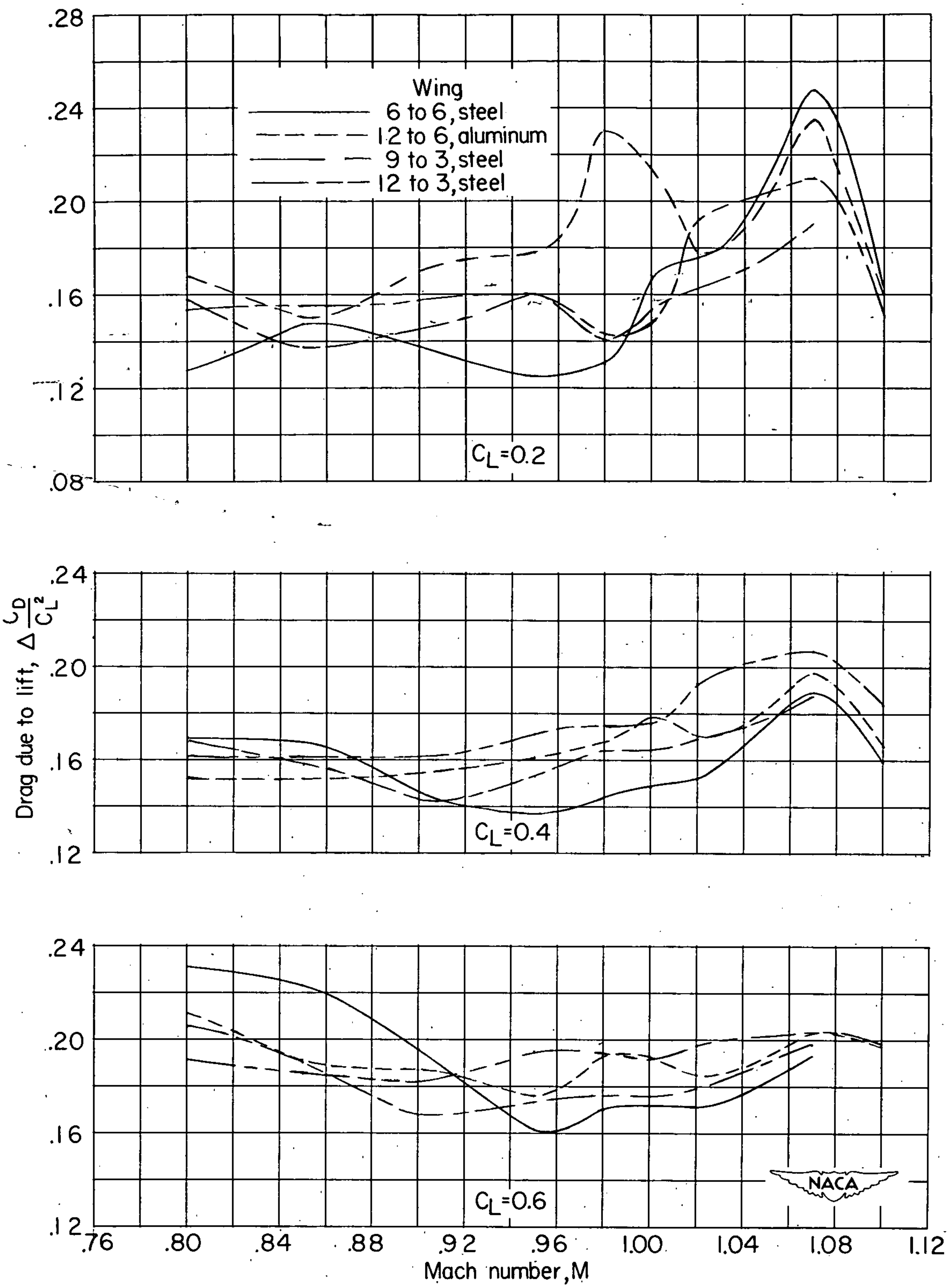


Figure 13.- Effect of spanwise taper in thickness ratio on drag due to lift.

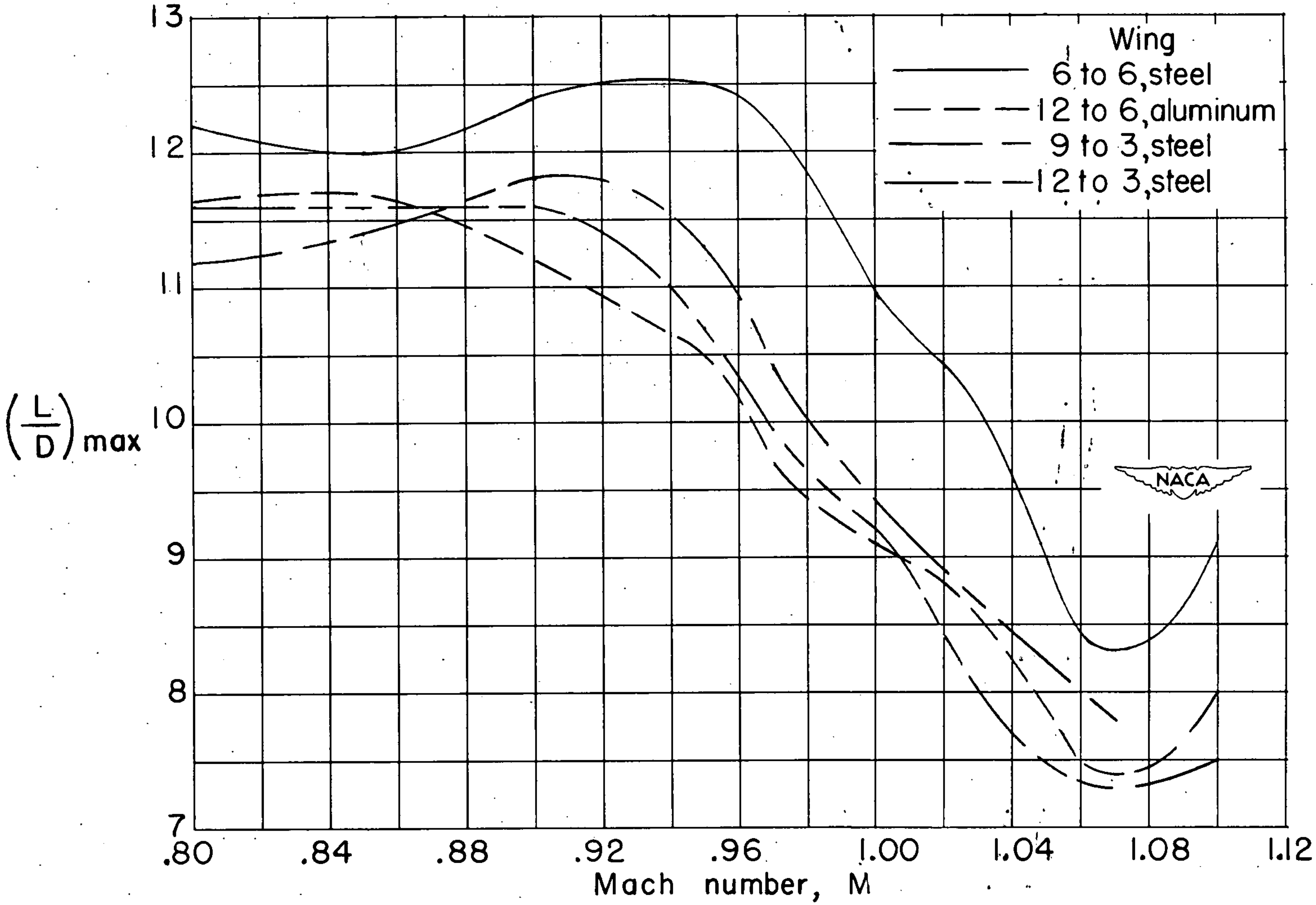


Figure 14.- Effect of spanwise taper in thickness ratio on the variation of maximum lift-drag ratio with Mach number.

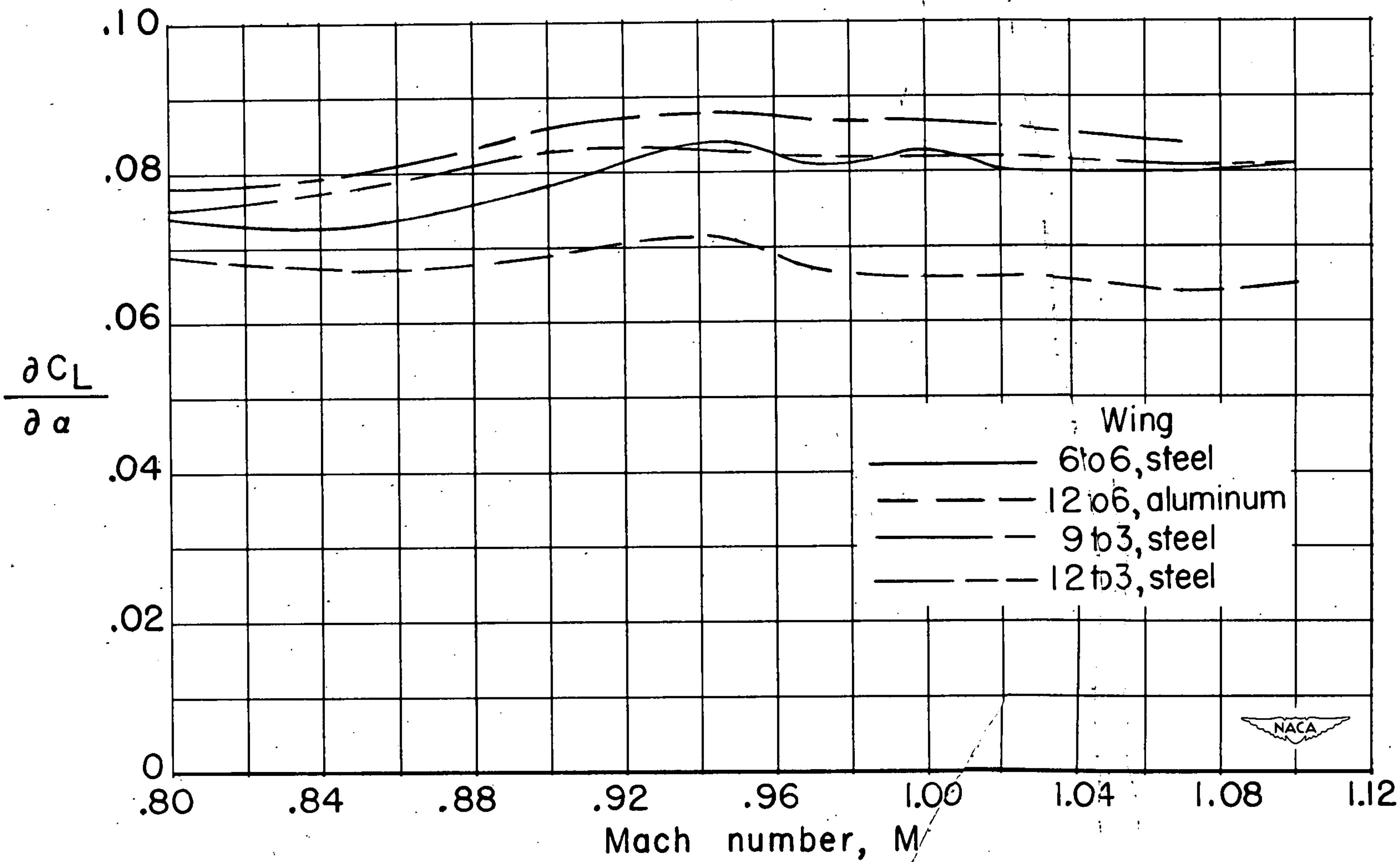


Figure 15.- Effect of spanwise taper in thickness ratio on the variation of lift-curve slope with Mach number.

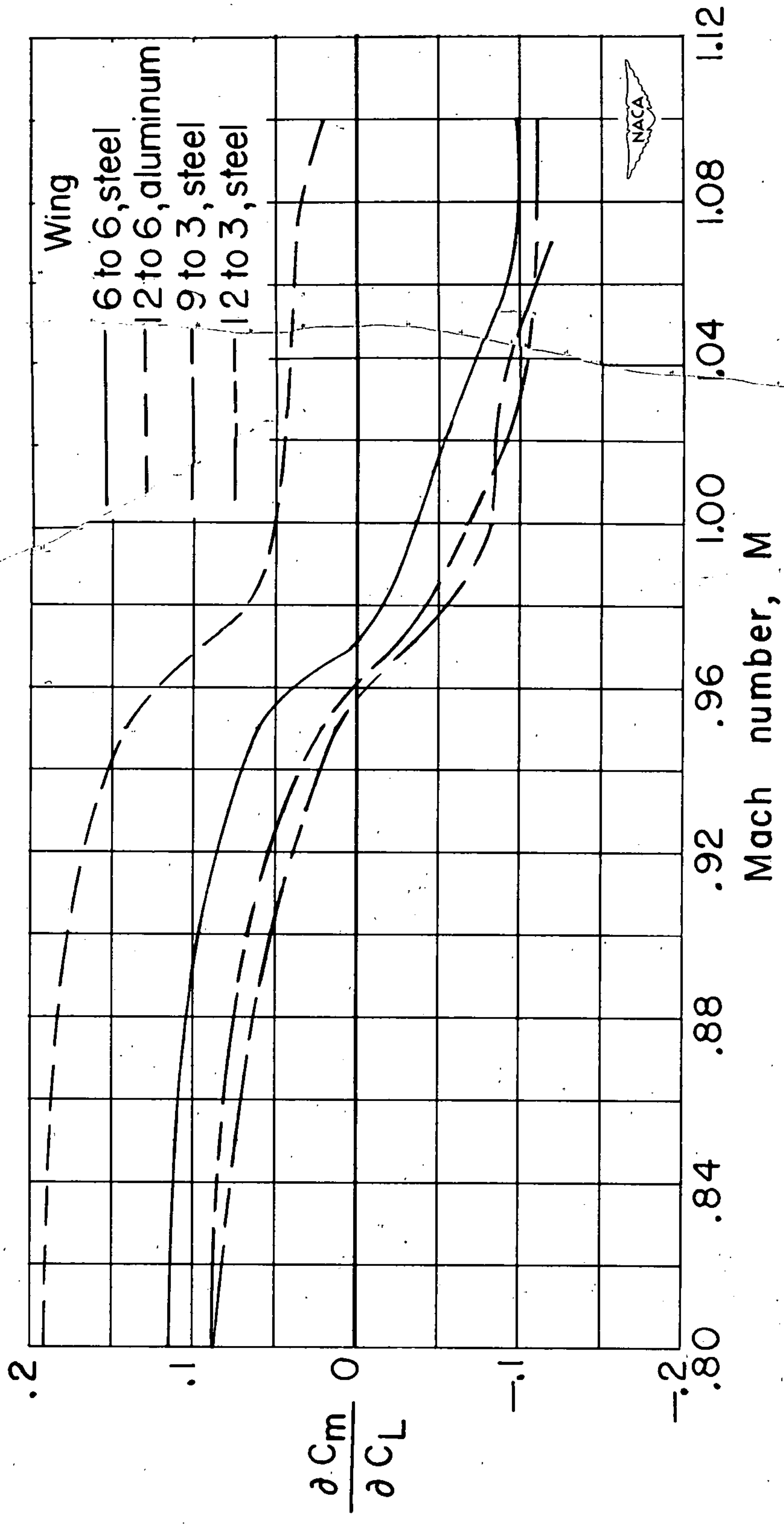


Figure 16.- Effect of spanwise taper in thickness ratio on the variation of the static-longitudinal-stability parameter with Mach number.

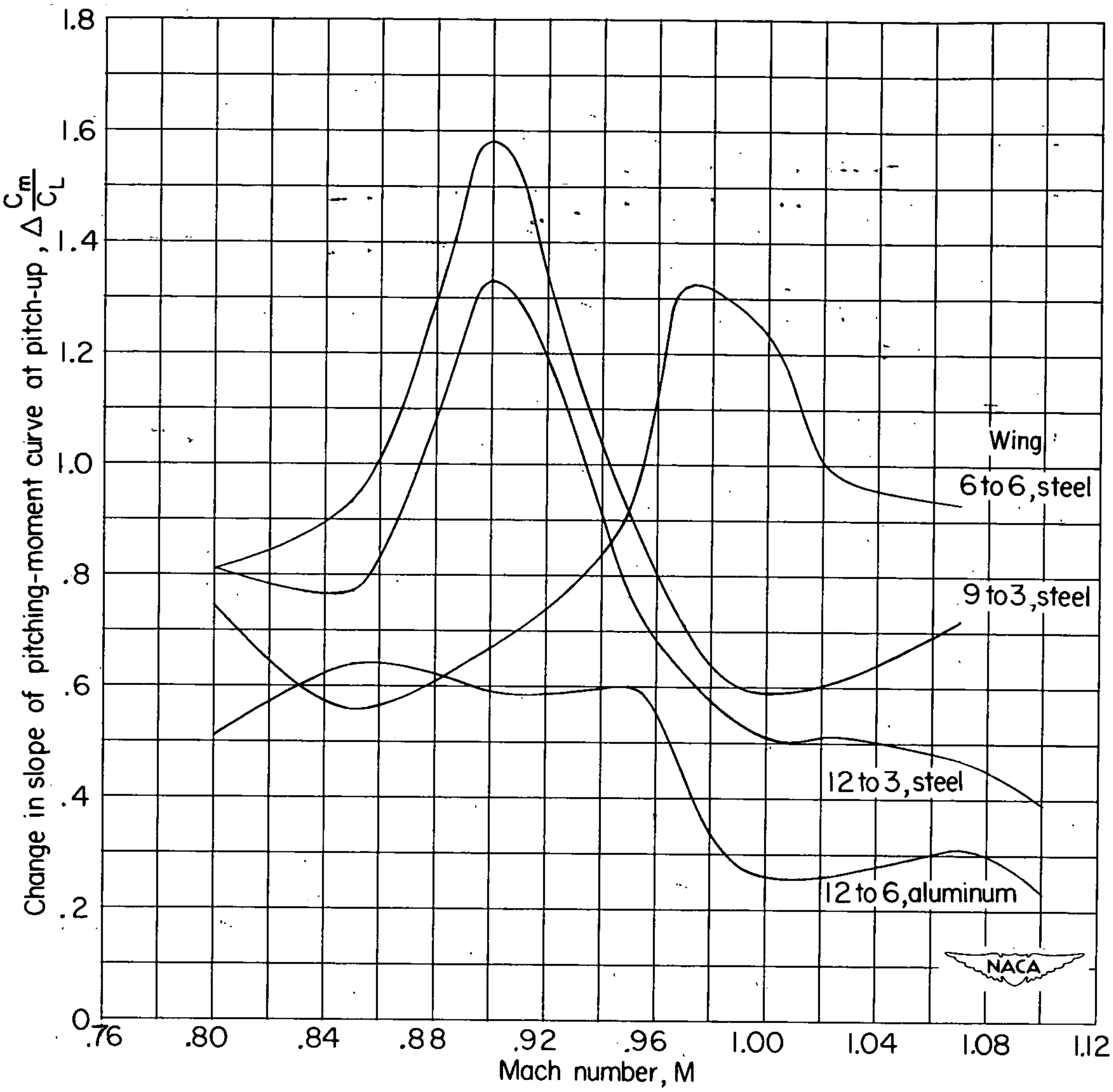


Figure 17.- Effect of spanwise taper in thickness ratio on the changing slope of the pitching-moment curve at pitch-up.

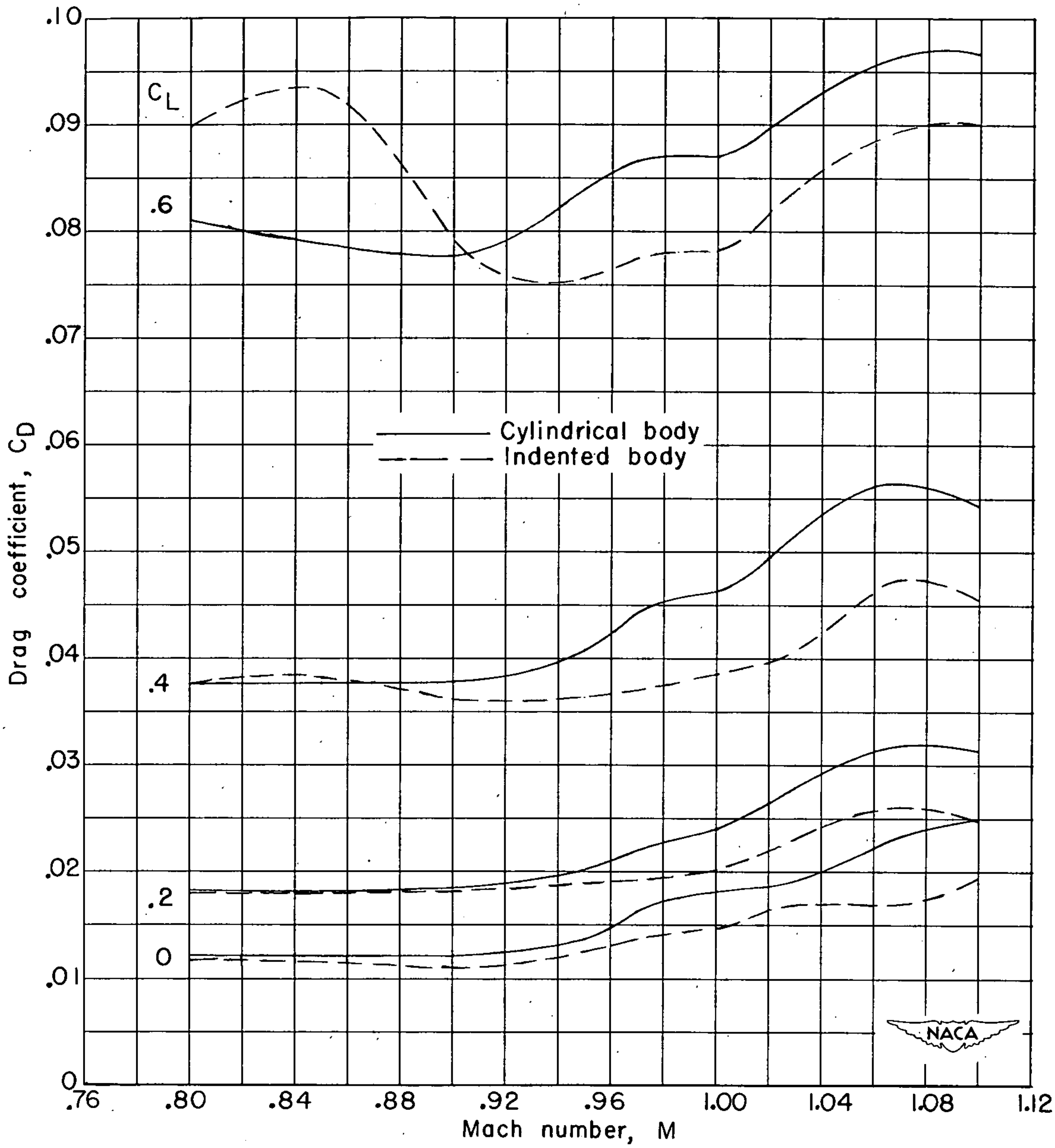


Figure 18.- Effect of body indentation on the variation of drag coefficient with Mach number for several lift coefficients.

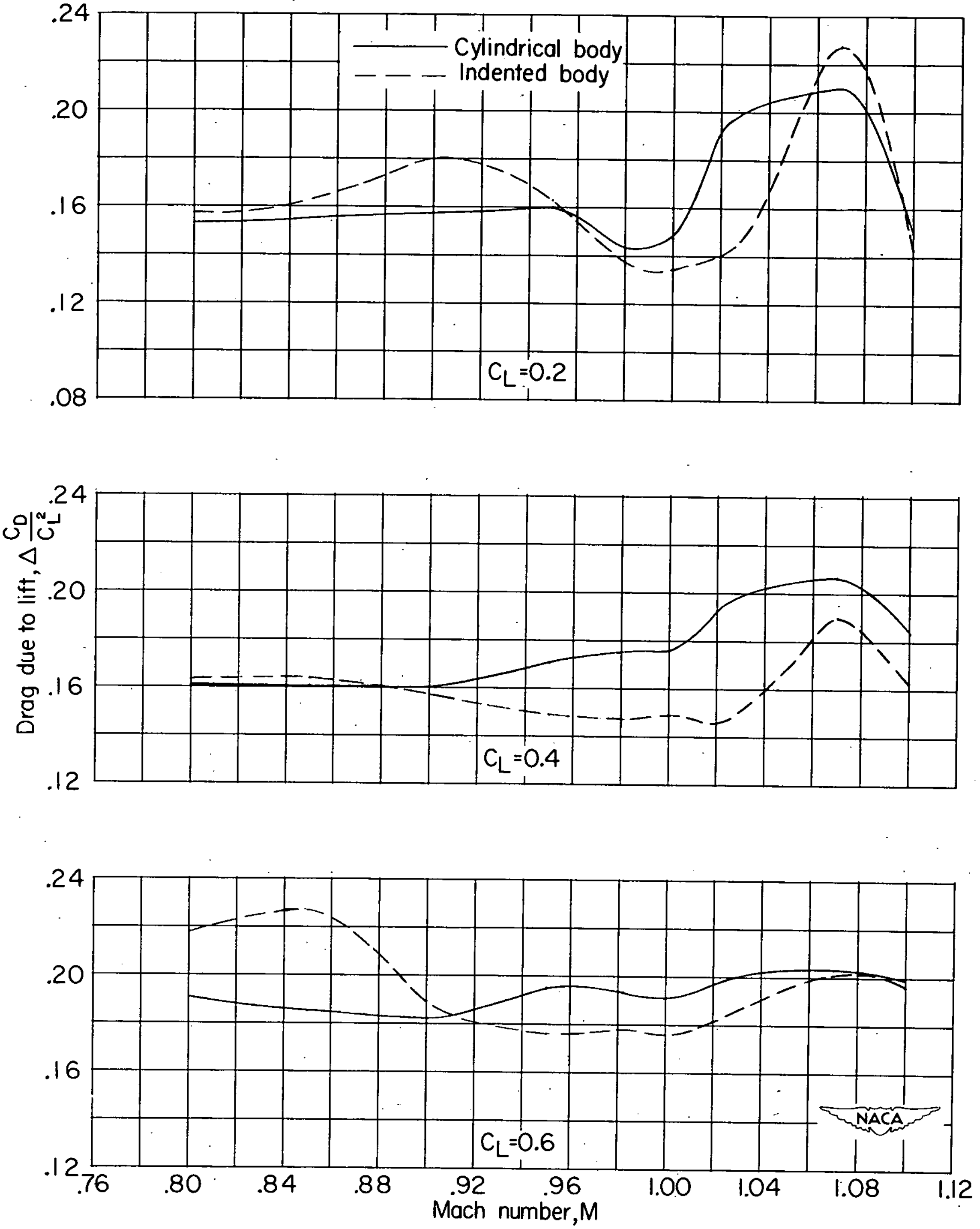


Figure 19.- Effect of body indentation on drag due to lift.

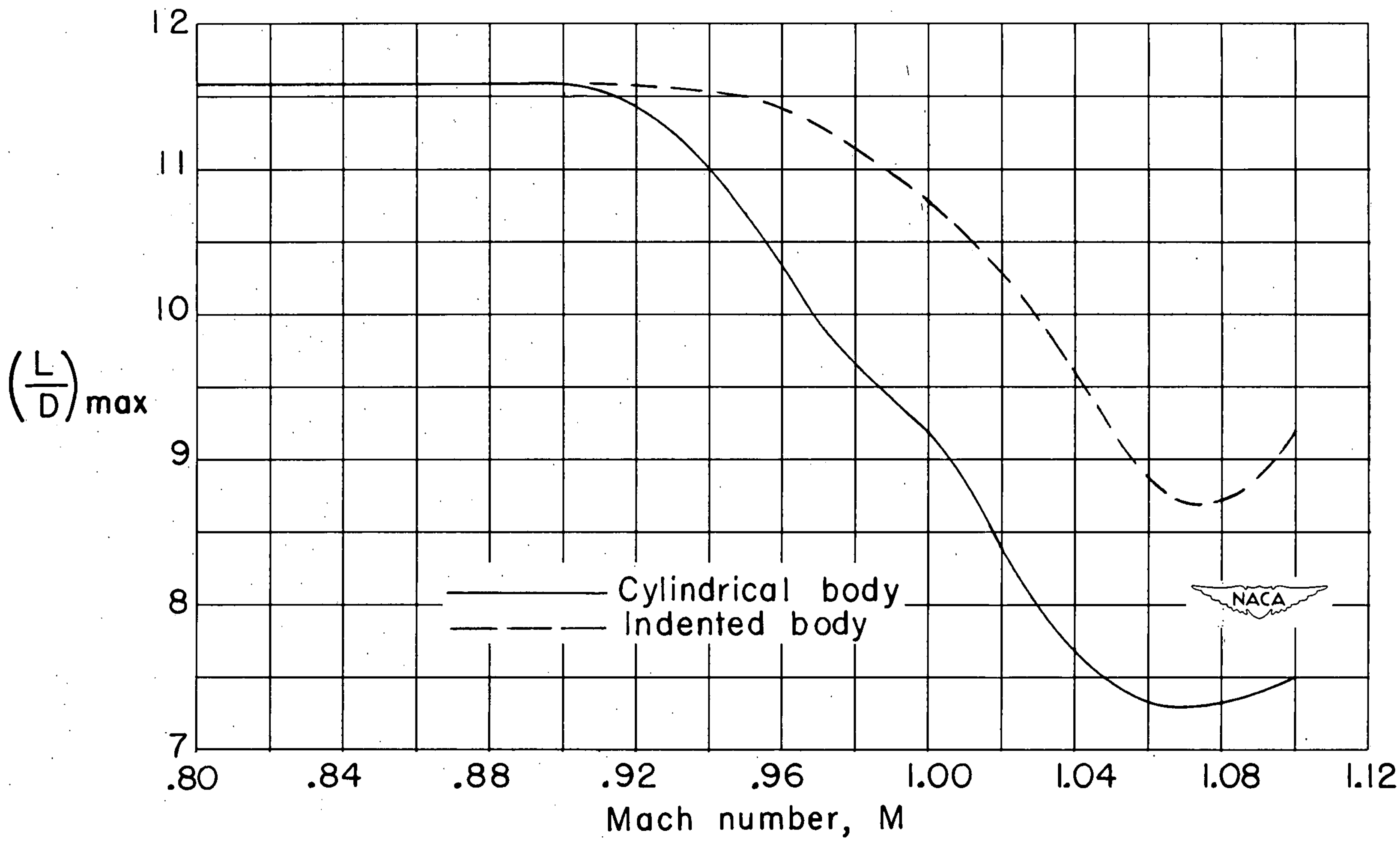


Figure 20.- Effect of body indentation on the variation of maximum lift-drag ratio with Mach number.

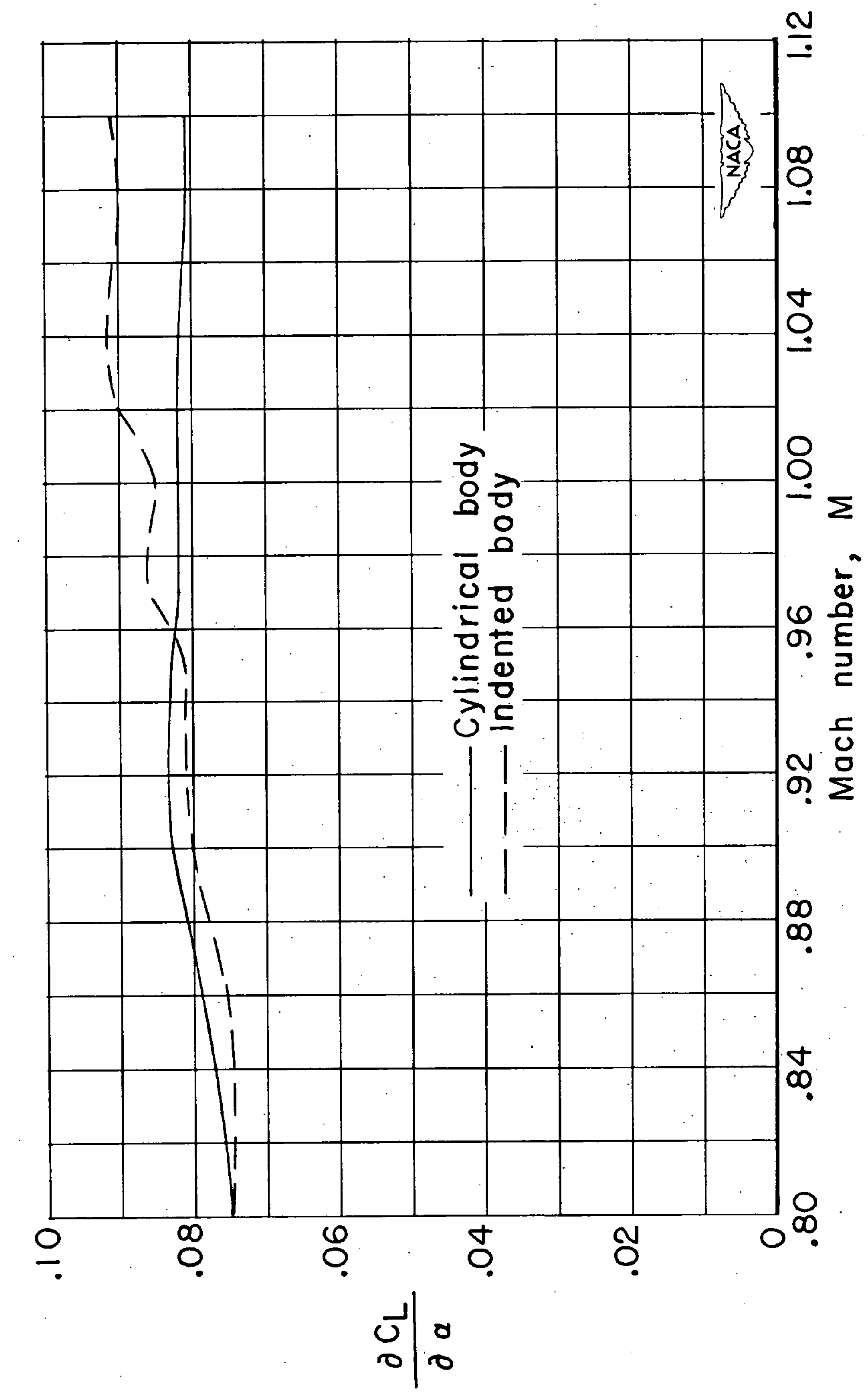


Figure 21.- Effect of body indentation on the variation of lift-curve slope with Mach number.

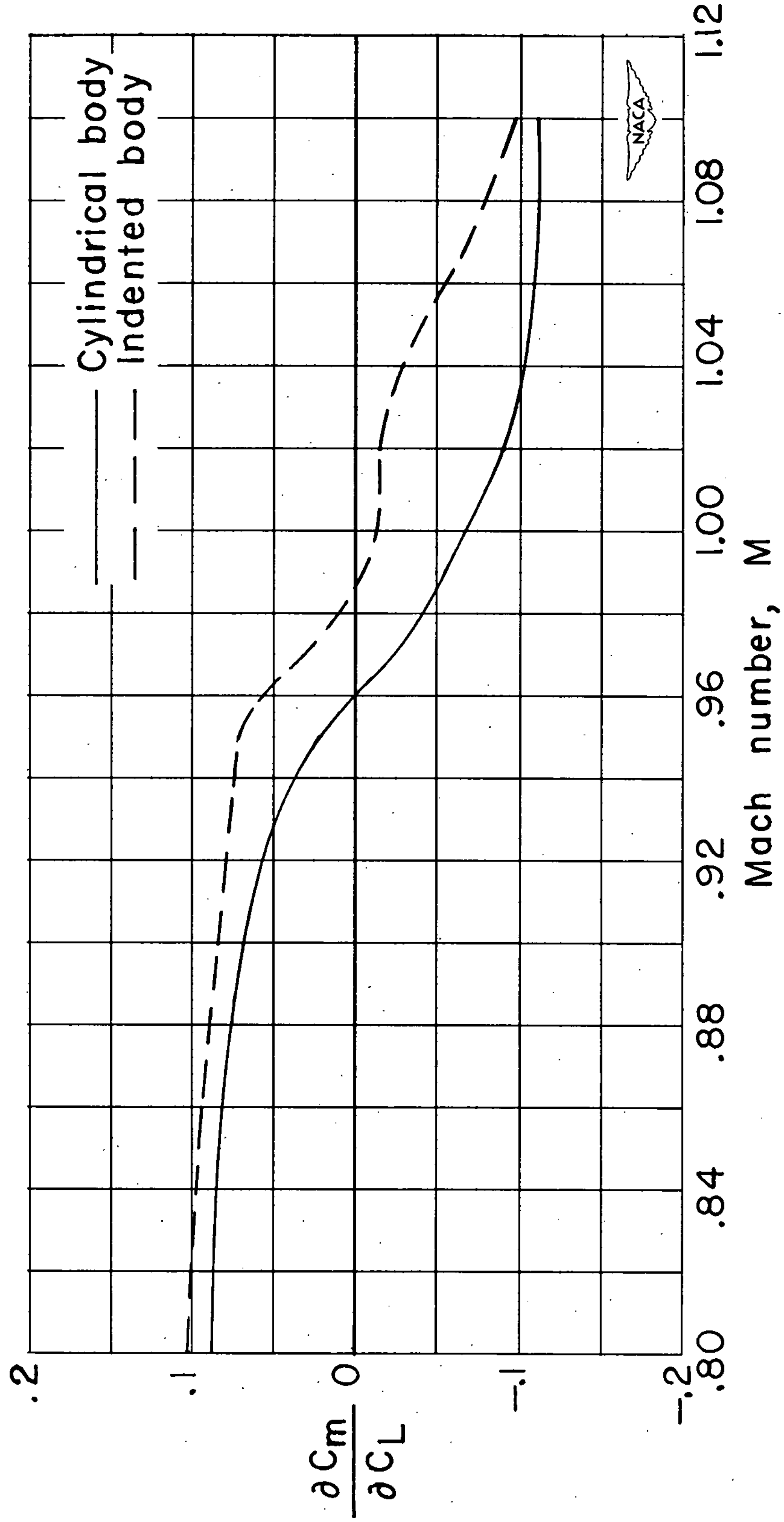


Figure 22.- Effect of body indentation on the variation of the static-longitudinal-stability parameter with Mach number.